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EFFICIENCY OF A RADIAL-FLOW EXHAUST-GAS TURBOSUPERCHARGER TURBINE WITH A 12.75-INCH TIP DIAMETER

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NACA AIRCRAFT ENGINE RESEARCH LABORATORY

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

EFFICIENCY OF A RADIAL-FLOW EXHAUST-GAS TURBOSUPERCHARGER TURBINE WITH A 12.75-INCH TIP DIAMETER

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SUMMARY

An investigation has been made of the effect on the performance of a radial-flow exhaust-gas turbosupercharger turbine with a 12.75-inch tip diameter of various inlet pressures, inlet temperatures, wheel speeds, pressure ratios, and cooling-air flows. For a given blade-to-jet speed ratio, variation in pressure ratio from 1.5 to 4.0 and inlet temperature from 800° to 1200° R had only a small effect on turbine efficiency. For blade-to-jet speed ratios of 0.5 and 0.6, the efficiency increased 4.5 points as inlet pressure increased from 20 to 50 inches of mercury absolute. Cooling-air flow had no measurable effect on turbine efficiency within the accuracy of the tests in the test range: namely, ratios of cooling-air flow to turbine gas flow from 0 to 14 percent, turbine pressure ratio of 2.0, turbine inlet total pressures from 15 to 40 inches of mercury absolute, and inlet temperatures from 800° to 2000° R.

INTRODUCTION

The radial-flow exhaust-gas turbine investigated has many features that are radically different from those of the conventional axial-flow turbine. The radial-flow turbine wheel runs with considerable reaction and incorporates drilled cooling-air passages through the disk. Performance tests of the conventional axial-flow turbine have been reported in references 1 and 2, but very little data have been published on the radial-flow-type turbine (reference 3) and no data are available that show the effect of cooling-air flow on turbine efficiency.

An investigation was therefore made at the NACA Cleveland laboratory during July and August 1945 at the request of the Bureau of Aeronautics, Navy Department, to determine the basic efficiency and also to investigate the effect of cooling-air flow on turbine performance. Curves of efficiency and air flow are presented that cover a range of turbine speeds from 3000 to 17,000 rpm, inlet pressures from 15 to 50 inches of mercury absolute, inlet temperatures from 800° to 2000° R, pressure ratios from 1.5 to 4.0, and cooling-air flows from 0 to 10 percent of the turbine gas flow.

TURBINE ASSEMBLY

A photograph of the setup for the investigation of the radial-flow exhaust-gas turbine is shown in figure 1. The nozzle box, the turbine wheel with cooling-air passages and shaft, the wheel-case center cover, and the rear-bearing support (turbine end of shaft) are shown in figure 2. The nozzle box is a double tangential-inlet radial-flow type. The turbine wheel has a comparatively small number of blades (17) and runs with considerable reaction; the driving fluid enters the turbine wheel radially and is discharged axially.

The compressor impellers and diffusers and the oil pump were removed. The waste gate was replaced by a stainless-steel seal to eliminate leakage. The oil passages in the front-bearing housings (compressor end of shaft) were reworked to permit lubrication of the bearings from external oil pumps. An extension shaft was inserted into and fastened to the compressor end of the hollow turbine shaft with dowel pins. The power was transmitted through a flexible coupling to a high-speed eddy-current dynamometer. Distortion of the wheel-case center cover and consequent rubbing on the turbine wheel at simulated altitude conditions were prevented by installing a chamber between the nozzle box and rear-bearing support and venting it to the turbine discharge duct. Figure 3 shows these modifications.

The clearance between the air seal (fig. 3) and the back of the turbine wheel was set at 0.005 inch cold and the clearance between the trailing edge of the turbine-blade tips and the turbine casing was 0.044 to 0.051 inch cold. The distance from the upstream end of the inner cylinder of the annular exhaust chamber to the turbine wheel was seven-eighths inch.

The wheel was designed to be cooled by air bled from the first-stage compressor to increase the life of the turbine wheel at elevated temperatures and to permit safe operation at inlet-gas temperatures up to 1700° R. Because the compressors were removed, cooling air had to be provided from an external source. The

compressor inlet and one outlet were blanked off and cooling air from the laboratory air supply was introduced through the other compressor outlet. Cooling-air flow was measured by a thin-plate orifice. Fifty-one cooling-air passages are located in the turbine wheel in planes slightly less than 90° from the turbine axis. (See detail A of fig. 3.) These passages terminate in groups of three into 17 other drilled passages, each one under the root of a blade and roughly parallel to the root. The cooling air enters the wheel near the shaft and discharges on the downstream side of the turbine wheel near the axis. The air-flow path is indicated by arrows in figure 3. The cooling-air passage outlets are shown in figure 2(b). The turbine was driven by hot gas at various temperatures and pressures from a hot-gas producer similar to the one described in reference 1.

A plenum chamber in the form of an inverted U constructed from 18-inch-diameter ducts and covered with 3 inches of insulation was attached to the nozzle box to insure an equal gas flow through both nozzle-box inlets. This arrangement is shown in figure 1. The hot gas entered at the center of the top of the chamber and flowed down both legs. The nozzle-box inlet ducts extended into the legs of the plenum chamber and the upstream ends were bellmouthed to induce a smooth gas flow.

INSTRUMENTATION

A thin-plate orifice was used to measure air flow to the gas producer. Fuel flow was measured with a calibrated rotameter.

Inlet-gas temperature was measured by four quadruple-shielded chromel-alumel thermocouples, two placed in each inlet to the nozzle box. The average of these four thermocouple readings was assumed to be the total temperature at the nozzle-box inlets. The maximum difference in thermocouple readings was ±5° F. Inlet static pressure was taken as the average of the readings of eight pressure taps, four located in the same cross section in each of the two nozzle-box inlet ducts as indicated in figure 3. These pressure readings had a maximum variation of ±0.1 inch of mercury. The total inlet pressure was computed from the measured static pressure and the total temperature by use of the continuity equation.

An annular chamber having the same cross-sectional area as the annular area swept by the discharge edges of the turbine blades plus the annular area that corresponds to the clearance between the trailing edge of the blade tips and the turbine casing was provided at the turbine discharge. Three banks of static pressure taps, 16 taps in each bank, were installed 120° apart in the annular

chamber. Six taps of each bank were installed in the outer cylinder of the annular chamber and 10 taps in the inner cylinder. These taps were spaced 0.75 inch and the six taps on the downstream end of the inner cylinder of the chamber were directly opposite the six taps in the outer cylinder of the annular chamber. The annular chamber and one bank of pressure taps are shown in figure 3. The turbine static discharge pressure was taken as the average of the readings of the six pressure taps lying in the plane passing through taps 1 and 11 (figure 3) and perpendicular to the axis of the turbine.

Dynamometer torque measurements were made with an NACA balanced-diaphragm torque indicator to the nearest 0.204 foot-pound. Turbine speed was measured to the nearest 10 rpm by two chronometric tachometers, each driven by its own tachometer generator turning at one-tenth turbine speed. The method recommended by the A.S.M.E. of estimating the accuracy of measurement of air flow gives a probable error of ±1.2 percent.

SYMBOLS

The following symbols are used in the report:

A_n actual turbine nozzle outlet area (sq ft)

g acceleration due to gravity, 32.2 (ft)/(sec)^2, or dimensional constant, 32.2 (lb)/(slug)

M_m theoretical maximum mass flow of gas that can be passed through convergent nozzle of 21.5-square-inch throat area, (slugs)/(sec)

M_t mass flow of air plus fuel, (slugs)/(sec)

N turbine speed, (rpm)

p_d static pressure of turbine discharge, (in. Hg absolute)

p_i total pressure at nozzle-box inlet, (in. Hg absolute)

R_b gas constant for combustion products, (ft-lb)/(lb-$^\circ$R)

T_i total temperature at nozzle-box inlet, ($^\circ$R)

u blade tip speed, (fps)

v theoretical jet speed, (fps)

W_c weight flow of cooling air, (lb)/(sec)

W_t weight flow of air plus fuel, (lb)/(sec)

γ ratio of specific heats

η turbine efficiency defined as ratio of shaft power to theoretical power computed from total temperature and pressure at turbine inlet and static pressure at turbine discharge

η' turbine efficiency defined as ratio of shaft power to difference between theoretical power (as defined for η) and kinetic power where kinetic power is calculated from average axial component of velocity at turbine discharge

δ ratio of turbine inlet pressure to NACA standard sea-level pressure, $p_1/29.92$

θ ratio of turbine inlet temperature to NACA standard sea-level temperature, $T_1/519$

TEST CONDITIONS

The fundamental efficiency of the turbine was determined by tests without cooling air. These tests were limited to an inlet temperature of 1200° R. The approximate test conditions were as follows:

Total inlet pressure, p_1 (in. Hg abs.)	Total inlet temperature, T_1 (°R)	Pressure ratio p_1/p_d
15	1200	1.5, 2.0
20	1000	1.5
30	800 1000 1200	1.5, 2.0, 3.0, 4.0
30	900 1100	2.0, 4.0
40 50	1000 1000	1.5, 3.0, 4.0

At each condition, data were taken over a range of speeds up to the maximum obtainable, but the speed was limited to 17,000 rpm by the manufacturer.

The gas temperatures for these tests were relatively low and resulted in very low fuel-air ratios; consequently, the gas properties differed little from those of air at these temperatures. The turbine efficiency η based on the total inlet pressure and temperature and the static discharge pressure was calculated by using a table of the thermodynamic properties of air from reference 4 and the equations of reference 5. The efficiency η' based on the difference between the total available energy calculated from the static discharge pressure and total inlet temperature and pressure and the kinetic energy of the average axial component of discharge velocity was calculated by the method of reference 1. Values of R_b and γ, taken from reference 6, were used to calculate the average axial component of the discharge velocity.

Additional tests were made at a constant pressure ratio of 2.0 to investigate the effect of cooling air on turbine efficiency. The following table shows the approximate conditions for each test:

Total inlet pressure, p_i (in. Hg. abs.)	Total inlet temperature, T_i (°R)	Cooling-air flow W_c (lb/sec)
15	1200	0, 0.095, 0.195
30	800	0, 0.095, 0.196, 0.330
	1200	0, 0.095, 0.196, 0.330
	1600	0.195, 0.330, 0.410
	2000	0.330, 0.410
40	1200	0.095, 0.196, 0.330

At each test condition the speed was varied up to the maximum obtainable but limited to 17,000 rpm. The cooling-air flows selected were chosen to insure safe operation of the turbine and were not necessarily the minimum flows required for cooling.

At the conclusion of this test program, a sudden increase in air flow of about 2 percent was noted. Inspection of the nozzle box revealed several radial cracks about one-half inch long and one-sixteenth inch wide in the casting that forms the waste-gate nozzles. The stress introduced by the waste-gate seal clamped over the casting may possibly have been the cause of these cracks.

RESULTS

The results of the tests without cooling air are shown in table I.

Turbine efficiency η is plotted against blade-to-jet speed ratio in figures 4 and 5. Figure 4 demonstrates the effect of pressure ratio for three inlet total gas temperatures and figure 5 shows the effect of inlet temperature and pressure on turbine efficiency. The peak efficiency occurs at a blade-to-jet speed ratio of about 0.66.

Figure 6(a) shows that for blade-to-jet speed ratios lower than 0.6 the turbine efficiency increases with increase in pressure ratio up to 3.0 and then decreases. For a blade-to-jet speed ratio of 0.4 the increase is about 2 points for an increase in pressure ratio from 1.5 to 3.0. For a blade-to-jet speed ratio of 0.6, however, the efficiency decreases about 2 points when the pressure ratio increases from 1.5 to 3.0. Figure 6(b) shows the effect of variation in inlet temperature on turbine efficiency. The turbine efficiency varies only slightly with inlet temperature. Over the range of inlet temperatures from 800° to 1200° R the maximum difference in efficiency was 1.5 points. The efficiency increases with inlet pressure as shown in figure 6(c). The greatest increase of efficiency occurs at blade-to-jet speed ratios of 0.5 and 0.6 and is about 4.5 points over a range of inlet pressures from 20 to 50 inches of mercury absolute.

In figure 7 the turbine efficiency is plotted against the Reynolds number factor $p_1/T_1^{1.1}$ derived in reference 1. The curves are shown for constant blade-to-jet speed ratios from 0.2 to 0.6 and pressure ratios from 1.5 to 4.0. The inlet-pressure range shown is from 15 to 50 inches of mercury absolute and the inlet-temperature range is from 800° to 1200° R. The derivation of the Reynolds number factor in reference 1 neglects mechanical losses, bearing friction, and windage, which is a logical assumption when small turbines having antifriction bearings are considered. Friction losses are, however, considerably higher for journal-type bearings and would have proportionally greater influence on the results. No correction has been made in the data reported here for bearing friction. Although figure 7 shows a good correlation of the data, it cannot be offered as evidence of the effect of Reynolds number on turbine efficiency because of the small variation of the efficiency with the Reynolds number factor and the unknown effect of bearing friction.

The turbine mass flow may be correlated by plotting the gas-flow factor $\frac{M_t}{p_1}\sqrt{gR_b T_1}$ (reference 1) against the speed factor $N/\sqrt{\theta}$ for any pressure ratio. For convenience of calculation, the gas-flow factor is reduced to the form $(M_t\sqrt{\theta})/\delta$ and plotted against the

speed factor for various pressure ratios in figure 8. All the data over the range of inlet pressures and temperatures is correlated on this plot within an accuracy of $1\frac{3}{4}$ percent. The variation of the gas-flow factor $(M_t \sqrt{\theta})/\delta$ with pressure ratio is shown on cross plot figure 9. The occurrence of reaction is indicated by the fact that the gas-flow factor continues to increase as the pressure ratio increases above 1.83.

The ratio of the turbine mass flow M_t to the critical mass flow M_m at any given inlet pressure and temperature is plotted against the speed factor $N/\sqrt{\theta}$ in figure 10. The critical mass flow is defined as the theoretical maximum flow that could be passed through a convergent nozzle having a discharge area equivalent to the turbine nozzle discharge area (21.5 sq in.) and is calculated from the following equation:

$$M_m = \frac{70.73\, p_1 A_n}{\sqrt{g R_b T_1}} \left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}} \sqrt{\frac{2\gamma}{\gamma+1}}$$

Although γ and R vary with inlet temperature, their variation with temperature over a range from 800° to 1200° R resulted in a difference in M_m of less than one-half percent. Consequently, for all practical purposes equation (1) reduces to

$$(M_m \sqrt{\theta})/\delta = 0.228 \text{ (slug)/(sec)}$$

where

$$\gamma = 1.380$$

$$R_b = 53.25 \text{ (ft-lb)/(lb)(°R)}$$

The plot of figure 10 correlates all the data over the entire range of test conditions. Figure 11 is a cross plot of figure 10 and shows that the ratio M_t/M_m approaches a value of 0.875 at a pressure ratio of about 4.0.

Turbine efficiency η' is plotted against blade-to-jet speed ratio for various inlet temperatures and pressure ratios in figure 12 and data are shown for the same conditions as those of figure 4. In this case the efficiency η' increases with pressure ratio for each inlet temperature.

A plot of the efficiency ratio η'/η against the blade-to-jet speed ratio for various pressure ratios is shown in figure 13, which correlates all the data within an accuracy of 1 percent. The efficiency η' varies from 1.04 to 1.16 times the corresponding values of η. The greatest increase occurs at the combination of low blade-to-jet speed ratios and high pressure ratios.

The results of the tests using turbine-wheel cooling air are shown in figure 14, a typical curve of turbine efficiency plotted against blade-to-jet speed ratio for various cooling-air flows from 0 to approximately 0.33 pound per second. These data were taken with an inlet pressure of approximately 30 inches of mercury absolute and an inlet temperature of 800° R. It is evident from this plot that for the range investigated cooling-air flow has no measurable effect on turbine efficiency within the accuracy of the data.

The effect of cooling air on the turbine efficiency is shown in the following summary table:

Inlet total temperature, T_1 (°R)	Inlet total pressure, p_1 (in. Hg abs.)	Blade-to-jet speed ratio u/v	Cooling-air flow (percent turbine gas flow)	Turbine efficiency η
800	29.8	0.6	0 - 7	0.675
1200	29.8	.6	0 - $8\frac{1}{4}$	.67
1600	29.8	.5	$5\frac{1}{2}$ - $12\frac{1}{4}$	.61
2000	29.8	.45	$10\frac{1}{2}$ - $13\frac{3}{4}$	.58
1200	39.9	.55	0 - $6\frac{1}{4}$	.65
1200	29.8	.55	0 - $8\frac{1}{4}$	.65
1200	14.8	.55	0 - 10	.61

No variation in efficiency with cooling-air flow is noted in this table. Figure 14 and this table show only the effect of the cooling-air flow on the performance of the turbine proper. A complete evaluation of the cooling-power loss must include the pumping horsepower required to force the cooling air through the cooling passages. Table II shows a summary of the test data using cooling air and

inoludes the oooling-air flow, preesure drop from the oompreesor housing to the turbine discharge preseure, and cooling-air inlet temperature meaeured just before entranoe to the turbine wheel. From these data the pumping horsepower can be computed. A oorrelation of thie oooling data wae not attempted becauee the temperature variation of the cooling air ae it paeeed through the oooling paesagee wae unknown.

SUMMARY OF RESULTS

From efficienoy teete of a radial-flow exhauet-gas turbo-supercharger turbine with a 12.75-inch tip diameter over a range of pressure ratios, inlet temperaturee, inlet pressuree, and cooling-air flowe, the following reeulte were obtained:

1. The variation of efficiency with preeeure ratio over the range from 1.5 to 4.0 wae small (2 pointe or leee) for any given blade-to-jet epeed ratio.

2. The turbine effioiency varied only elightly with inlet temperature. Over the inlet-temperature range from 800° to 1200° R, the maximum difference in efficiency wae 1.5 pointe.

3. The efficiency increaeed about 4.5 pointe at blade-to-jet epeed ratioe of 0.5 and 0.6 ae inlet preeeure increaeed from 20 to 50 inchee of mercury abeolute.

4. The mase flow through the turbine increaeed with preeeure ratio and approached a limiting value at a preeeure ratio of about 4.0. At a pressure ratio of 4.0, the ratio of the turbine maee flow to the theoretical maximum mase flow wae 0.875.

5. Teete made with turbine inlet-gae preeeuree from 15 to 40 inchee of mercury abeolute, inlet-gae temperatures from 800° to 2000° R, a preseure ratio of 2.0, and cooling-air flowe up to 14 percent of the turbine gae flow show that cooling-air flow had no meaeurable effoot on turbine effioiency.

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TABLE I - SUMMARY OF TEST DATA WITHOUT COOLING AIR

Pressure ratio p_1/p_8	Total inlet pressure (in. Hg abs.) p_1	Total-inlet temperature T_1 (°R)	Turbine speed N (rpm)	Blade-to-jet speed ratio u/v	Shaft power (hp)	Gas flow W_8 (lb/sec)	Turbine efficiency η	Turbine efficiency η'
1.48	14.8	1200	3,000	0.135	18.7	1.63	0.210	0.219
1.49	14.8		5,980	.266	27.2	1.65	.373	.389
1.50	14.8		7,440	.329	33.0	1.86	.445	.465
1.50	14.8		9,030	.400	37.8	1.86	.509	.531
1.49	14.8		10,490	.466	40.8	1.86	.564	.580
1.50	14.8		11,900	.528	44.0	1.86	.599	.624
1.50	14.8		4,010	.354	34.0	1.65	.460	.480
1.99	14.8	1200	3,000	0.104	32.5	1.87	0.169	0.175
1.99	14.9		6,010	.208	41.7	1.90	.299	.318
2.00	14.9		7,810	.268	41.2	1.91	.363	.385
2.00	14.9		9,000	.310	39.3	1.97	.420	.445
2.00	14.9		10,490	.362	46.2	1.92	.489	.497
2.00	14.9		12,000	.414	75.7	1.92	.536	.567
2.00	14.8		13,480	.464	66.3	1.91	.571	.603
2.02	14.9		15,040	.516	84.3	1.91	.594	.627
2.01	14.9		16,350	.562	87.1	1.91	.616	.650
1.50	19.8	1000	3,000	0.184	20.2	2.41	0.225	0.235
1.50	19.9		6,010	.291	38.5	2.42	.427	.446
1.50	19.9		7,510	.363	44.0	2.41	.488	.508
1.50	19.8		9,010	.437	49.7	2.43	.550	.574
1.50	19.8		10,510	.510	52.7	2.39	.594	.618
1.49	19.8		11,970	.564	54.5	2.37	.627	.652
1.50	19.7		13,500	.656	56.7	2.35	.640	.665
1.50	19.8		11,560	.562	53.4	2.38	.609	.633
1.49	29.7	800	2,990	0.164	29.5	4.02	0.252	0.263
1.56	29.7		5,990	.326	55.4	4.13	.454	.476
1.50	29.7		7,550	.411	65.5	4.14	.536	.560
1.50	29.7		9,010	.489	73.5	4.11	.604	.630
1.49	29.6		10,500	.575	78.7	4.06	.667	.698
1.48	29.6		11,960	.656	78.9	3.97	.683	.710
1.49	29.7		13,470	.735	78.4	3.99	.670	.697
1.49	29.8		14,970	.819	72.5	3.96	.627	.652
1.97	29.7	800	2,990	0.128	46.4	4.69	0.206	0.219
1.99	29.8		6,020	.255	66.7	4.71	.364	.411
2.00	29.7		7,510	.318	104.0	4.75	.448	.475
2.01	29.7		9,010	.380	120.9	4.72	.522	.552
1.99	29.7		10,490	.446	132.2	4.69	.583	.615
1.99	29.7		11,970	.508	143.5	4.75	.634	.656
1.99	29.7		13,490	.571	148.8	4.69	.652	.686
1.98	29.6		14,990	.638	151.2	4.63	.679	.714
1.98	29.7		17,000	.723	150.4	4.64	.671	.705
2.97	29.6	600	3,000	0.104	62.4	5.00	0.172	0.190
2.96	29.5		6,020	.206	117.7	5.04	.320	.352
3.01	29.6		7,520	.259	143.8	5.08	.386	.424
3.00	29.6		9,000	.311	187.2	5.09	.449	.491
2.99	29.7		10,500	.363	187.8	5.12	.502	.548
3.02	29.6		12,000	.413	208.5	5.11	.555	.604
3.01	29.6		13,500	.465	224.7	5.10	.609	.651
3.00	29.8		15,000	.515	237.1	5.09	.635	.686
2.96	29.6		16,990	.590	241.2	5.08	.656	.709
4.04	29.7	600	6,000	0.187	133.3	5.18	0.990	0.334
3.95	29.6		7,500	.236	161.5	5.16	.194	.405
4.00	29.6		9,000	.282	191.1	5.18	.435	.472
3.94	29.6		10,490	.330	214.6	5.20	.468	.530
3.93	29.7		12,000	.378	240.3	5.22	.523	.588
3.95	29.7		13,520	.428	262.3	5.20	.571	.640
3.93	29.7		15,040	.474	278.9	5.16	.614	.683
3.93	29.7		17,040	.537	293.4	5.21	.640	.713
1.49	29.8	1000	3,050	0.149	31.1	3.63	0.234	0.245
1.50	29.8		6,030	.293	57.5	3.69	.421	.440
1.49	29.7		7,520	.366	69.1	3.69	.506	.529
1.50	29.8		9,000	.436	77.8	3.71	.563	.588
1.50	29.9		10,490	.508	85.6	3.69	.626	.652
1.49	29.7		11,960	.567	88.4	3.61	.656	.683
1.49	29.6		13,490	.656	87.3	3.56	.665	.692
1.50	29.9		14,960	.725	86.7	3.59	.660	.687
1.95	29.7	1000	3,010	0.116	48.3	4.17	0.169	0.200
1.97	29.7		5,990	.229	87.5	4.20	.349	.370
1.98	29.7		7,510	.286	106.6	4.22	.421	.446
1.97	29.6		9,000	.343	122.4	4.24	.481	.510
1.99	29.7		10,480	.398	138.1	4.27	.539	.570
1.99	29.7		11,990	.455	152.4	4.24	.591	.625
1.99	29.7		13,500	.511	162.7	4.25	.630	.665
1.98	29.6		14,970	.569	166.5	4.22	.653	.688
1.98	29.8		16,990	.646	169.2	4.16	.673	.708
2.94	29.7	1000	2,980	0.093	61.6	4.49	0.152	0.169
2.95	29.6		6,010	.187	121.1	4.53	.295	.325
2.94	29.7		7,530	.234	147.1	4.55	.356	.393
2.96	29.6		9,010	.279	171.1	4.55	.414	.453
2.95	29.6		10,500	.326	192.5	4.55	.468	.511
2.96	29.6		11,990	.371	213.3	4.55	.513	.561
2.97	29.7		13,540	.418	234.5	4.55	.564	.613
2.96	29.6		15,010	.464	249.5	4.55	.601	.652
2.96	29.8		16,966	.527	262.5	4.55	.636	.666
2.95	29.9		12,010	.372	213.6	4.56	.516	.562
2.93	29.8		7,600	.237	147.0	4.53	.360	.395
4.21	29.8	1000	7,540	0.206	184.8	4.63	0.310	0.360
4.06	29.8		9,010	.251	193.1	4.59	.373	.426
4.02	29.9		10,500	.291	213.3	4.86	.428	.488
4.02	29.8		12,000	.335	246.9	4.68	.476	.541
3.98	29.7		13,490	.378	270.2	4.61	.527	.593
3.99	29.6		15,010	.420	291.6	4.60	.569	.638
3.96	29.8		17,040	.476	315.3	4.60	.614	.686
1.49	29.7	1200	3,000	0.134	32.9	3.32	0.214	0.223
1.49	29.7		6,000	.267	57.4	3.35	.388	.405
1.50	29.9		7,500	.332	69.7	3.47	.465	.468
1.56	29.7		8,990	.399	79.0	3.57	.529	.552
1.50	29.8		10,470	.465	86.6	3.55	.581	.606
1.50	29.8		11,960	.529	94.0	3.53	.631	.656
1.49	29.7		13,430	.596	93.0	3.29	.641	.667
1.50	29.8		14,960	.864	93.1	3.27	.642	.667
1.99	29.9	1200	3,050	0.106	48.6	3.82	0.175	0.186
1.99	29.8		6,010	.208	99.9	3.87	.331	.341
2.00	29.9		7,490	.258	110.4	3.88	.386	.410
2.01	29.9		9,030	.311	128.2	3.86	.447	.474
2.01	29.9		10,490	.363	183.2	3.89	.498	.527
1.99	29.7		11,990	.414	157.2	3.90	.551	.585
2.00	29.9		13,470	.464	171.9	3.91	.597	.631
2.01	29.9		14,910	.512	181.0	3.89	.628	.665
2.01	29.8		17,010	.564	186.6	3.86	.652	.687

Pressure ratio p_1/p_8	Total inlet pressure (in. Hg abs.) p_1	Total-inlet temperature T_1 (°R)	Turbine speed N (rpm)	Blade-to-jet speed ratio u/v	Shaft power (hp)	Gas flow W_8 (lb/sec)	Turbine efficiency η	Turbine efficiency η'
2.99	29.8	1200	3,010	0.065	64.9	4.11	0.144	0.159
2.99	30.0		6,000	.169	124.2	4.23	.273	.301
2.97	29.3		7,480	.211	150.1	4.14	.333	.364
2.99	29.9		9,010	.254	176.7	4.16	.389	.423
3.00	29.9		10,510	.295	190.5	4.17	.433	.475
3.01	29.9		12,000	.337	220.3	4.17	.479	.523
3.01	29.9		13,370	.376	241.5	4.17	.523	.570
3.01	29.8		14,950	.420	263.4	4.17	.570	.621
3.01	29.8		16,970	.476	281.9	4.15	.613	.665
4.21	29.8	1200	7,520	0.189	186.5	4.20	0.290	0.337
4.26	29.9		9,000	.225	198.5	4.21	.336	.392
4.29	30.0		10,460	.261	223.8	4.25	.377	.436
4.29	29.9		11,970	.299	250.9	4.24	.424	.488
4.00	29.9		13,460	.343	276.9	4.23	.467	.551
3.99	29.8		15,040	.384	304.7	4.23	.518	.606
3.99	29.9		17,010	.434	332.7	4.24	.565	.656
1.97	29.8	900	2,990	0.120	46.8	4.37	0.194	0.206
1.99	29.6		6,020	.241	86.6	4.40	.366	.382
1.99	29.6		7,520	.300	108.5	4.44	.439	.465
1.99	29.7		9,000	.359	119.1	4.43	.491	.519
2.00	29.6		10,510	.419	137.0	4.47	.559	.591
1.99	29.7		11,990	.480	147.4	4.46	.608	.641
2.00	29.6		13,480	.534	156.4	4.48	.640	.675
2.00	29.8		14,950	.595	161.8	4.40	.668	.703
2.00	29.8		17,000	.676	166.9	4.39	.666	.700
1.99	29.7		9,100	.364	125.6	4.48	.504	.534
3.99	29.7	900	7,530	0.222	164.0	4.86	0.337	0.386
4.01	29.7		9,000	.265	192.6	4.84	.396	.456
4.01	29.7		10,500	.310	218.5	4.87	.448	.507
3.96	29.8		12,020	.356	245.0	4.90	.502	.565
3.96	29.7		13,490	.400	268.5	4.84	.554	.620
3.97	29.8		15,000	.444	286.7	4.89	.591	.661
3.95	29.8		16,990	.503	306.4	4.89	.630	.702
1.98	29.9	1100	3,030	0.110	46.0	3.97	0.182	0.193
2.00	29.9		6,010	.217	90.5	4.04	.334	.354
2.00	29.9		7,550	.271	109.9	4.08	.401	.425
1.99	29.9		9,050	.327	126.7	4.08	.464	.491
2.00	29.8		10,500	.379	141.7	4.07	.518	.548
2.00	30.0		12,010	.433	156.5	4.08	.571	.603
2.00	29.6		13,500	.486	166.6	4.09	.612	.647
2.00	29.9		14,990	.540	176.1	4.06	.644	.680
1.99	29.9		16,966	.613	178.3	4.02	.663	.689
4.09	29.9	1100	7,550	0.200	168.0	4.44	0.305	0.359
3.94	29.7		9,000	.241	195.4	4.38	.367	.418
4.01	29.9		10,490	.279	222.4	4.41	.410	.467
3.99	29.8		12,000	.321	250.6	4.45	.459	.521
3.98	29.8		13,480	.366	275.2	4.40	.511	.576
3.98	29.6		15,000	.401	296.7	4.44	.545	.614
3.95	29.8		17,020	.455	324.3	4.44	.599	.670
1.48	39.4	1000	3,000	0.148	40.7	4.66	0.234	0.244
1.46	39.5		6,030	.296	78.8	4.66	.424	.443
1.49	39.7		7,540	.367	90.6	4.92	.498	.520
1.56	39.7		9,020	.439	101.1	4.93	.567	.592
1.50	39.7		10,466	.509	115.5	4.95	.625	.652
1.50	39.6		11,970	.579	122.5	4.90	.670	.697
1.50	39.7		13,470	.654	120.1	4.81	.675	.703
1.49	39.7		14,950	.730	115.9	4.76	.665	.691
1.46	39.7		17,000	.839	100.1	4.69	.596	.620
2.97	39.7	1000	3,020	0.094	85.6	5.94	0.158	0.175
2.97	39.6		6,020	.186	160.5	6.03	.292	.322
2.98	39.6		7,530	.233	197.0	6.01	.360	.394
3.00	39.7		9,040	.279	230.5	6.10	.432	.462
3.00	39.6		10,500	.324	260.0	6.07	.487	.510
2.99	39.5		12,000	.371	290.6	6.14	.536	.566
3.00	39.6		13,480	.416	318.6	6.10	.569	.619
2.98	39.6		14,940	.462	334.6	6.05	.607	.656
2.98	39.7		17,040	.527	356.6	6.00	.650	.704
4.11	39.7	1000	7,540	0.209	224.3	6.14	0.322	0.371
4.12	39.6		9,000	.250	261.4	6.18	.377	.428
4.13	40.0		10,466	.291	299.9	6.21	.426	.486
4.07	39.8		11,940	.332	334.2	6.22	.477	.541
4.03	40.0		13,490	.377	367.1	6.17	.531	.597
4.02	39.9		14,990	.419	399.6	6.20	.577	.647
4.00	39.9		16,990	.475	428.7	6.21	.614	.686
1.49	49.8	1000	2,990	0.146	53.0	6.06	0.238	0.249
1.50	49.7		6,030	.292	100.8	6.21	.435	.464
1.50	49.8		7,530	.364	119.1	6.18	.535	.557
1.56	49.6		8,970	.434	133.9	6.19	.582	.607
1.50	49.7		10,460	.507	146.7	6.18	.637	.664
1.50	49.8		12,020	.584	151.0	6.09	.671	.698
1.56	49.8		13,500	.655	154.8	6.08	.686	.714
1.50	49.8		14,960	.725	152.0	5.98	.684	.711
1.49	50.0		17,020	.831	140.2	5.96	.643	.669
2.94	49.6	1000	2,990	0.092	106.0	7.53	0.154	0.170
2.97	49.8		6,040	.187	205.5	7.53	.299	.308
2.98	49.6		7,520	.233	249.7	7.61	.361	.387
2.99	49.7		9,020	.279	286.9	7.59	.413	.452
2.99	49.4		10,470	.323	326.9	7.59	.469	.513
2.99	50.0		11,960	.370	363.3	7.63	.520	.567
3.02	49.9		13,490	.415	401.2	7.68	.566	.617
3.01	50.0		15,000	.462	425.7	7.59	.609	.660
2.99	49.9		16,990	.525	451.6	7.62	.648	.701
4.10	49.9	1000	7,520	0.209	277.8	7.70	0.219	0.366
4.04	49.9		9,000	.251	323.7	7.71	.276	.428
4.04	49.9		10,530	.294	371.7	7.81	.344	.484
4.01	50.0		12,010	.336	417.5	7.78	.381	.544
3.96	49.6		13,440	.377	451.7	7.78	.524	.590
3.97	49.6		14,966	.420	491.6	7.76	.569	.639
3.94	49.8		17,000	.478	527.5	7.76	.615	.687

TABLE II - SUMMARY OF TEST DATA WITH COOLING AIR

Pressure ratio p_1/p_6	Total inlet pressure p_1 (in. Hg abs.)	Total inlet temperature T_1 (°R)	Turbine speed N (rpm)	Blade-to-jet speed ratio U/V	Shaft power (hp)	Gas flow W_t (lb/sec)	Turbine efficiency η	Cooling-air flow W_c (lb/sec)	Cooling-air pressure drop (in. Hg)	Cooling-air inlet temperature (°R)
1.28	14.6	1200	3,000	0.104	22.3	1.29	0.162	0.096	1.74	606
1.99	14.6		6,010	.208	91.9	1.91	.301	.097	1.86	606
2.00	14.6		7,520	.259	51.9	1.92	.369	.097	1.94	606
2.00	14.6		9,030	.312	56.4	1.92	.415	.097	1.94	604
2.00	14.6		10,490	.361	85.4	1.93	.461	.097	1.90	604
2.00	14.6		11,980	.413	74.2	1.92	.526	.097	1.80	603
2.02	14.9		13,490	.461	80.9	1.94	.560	.097	1.69	602
2.00	14.9		16,330	.582	63.8	1.92	.591	.097	1.33	805
1.29	14.6	1200	3,000	0.104	22.6	1.89	0.164	0.192	4.80	562
1.99	14.6		6,000	.207	82.1	1.90	.302	.192	4.16	580
2.00	14.2		7,500	.258	51.7	1.91	.368	.193	4.16	578
2.00	14.2		9,000	.310	59.3	1.92	.420	.193	4.00	578
2.01	14.9		10,500	.360	66.7	1.92	.466	.193	3.87	576
2.00	14.9		12,000	.413	75.7	1.93	.533	.193	3.71	578
2.00	14.9		13,490	.464	80.7	1.93	.570	.129	3.53	578
2.01	14.6		15,080	.516	82.4	1.92	.581	.193	3.36	580
2.02	14.9		16,310	.559	86.9	1.92	.609	.193	3.22	582
1.28	29.7	800	2,280	0.127	46.1	4.66	0.206	0.096	1.12	563
1.28	29.7		3,990	.224	87.0	4.73	.340	.096	1.81	574
2.00	29.8		7,510	.319	104.7	4.73	.453	.097	2.14	574
1.99	29.8		8,980	.381	118.2	4.73	.516	.096	2.14	574
2.00	29.7		10,480	.444	131.6	4.74	.571	.097	2.06	573
1.99	29.7		11,960	.508	146.2	4.73	.640	.097	1.75	575
1.99	29.7		13,460	.570	152.4	4.70	.667	.097	1.42	576
1.99	29.8		14,930	.632	159.5	4.65	.683	.097	.95	580
1.99	29.7		17,060	.725	152.1	4.66	.673	.096	.16	582
1.98	29.6	800	2,970	0.127	46.2	4.67	0.209	0.193	2.63	570
1.99	29.6		5,020	.217	68.2	4.75	.339	.194	3.05	566
1.99	29.7		7,580	.319	105.7	4.75	.459	.194	3.36	566
1.98	29.5		8,990	.388	120.6	4.74	.537	.193	3.32	568
1.99	29.6		10,500	.446	133.7	4.73	.580	.193	3.30	570
2.00	29.7		11,970	.507	147.0	4.76	.633	.194	3.15	570
1.99	29.6		13,460	.571	152.7	4.71	.669	.193	2.69	572
1.99	29.6		15,000	.637	154.6	4.65	.685	.192	2.22	572
1.98	29.6		16,970	.722	151.8	4.62	.681	.192	1.63	572
1.99	29.8	800	2,990	0.126	46.1	4.69	0.206	0.331	2.73	566
1.99	29.9		4,990	.224	87.0	4.74	.372	.332	2.99	566
1.99	29.7		7,510	.318	103.2	4.74	.480	.331	3.01	566
1.99	29.8		8,980	.380	118.9	4.75	.530	.330	2.93	566
1.99	29.8		10,490	.445	131.9	4.74	.574	.331	2.89	566
2.00	29.7		12,020	.509	147.4	4.74	.618	.337	2.78	567
1.99	29.7		13,470	.571	151.0	4.73	.656	.333	2.61	568
1.98	29.9		15,000	.634	150.5	4.67	.666	.331	2.38	569
1.98	29.9		17,000	.724	148.7	4.63	.667	.343	1.95	572
1.28	29.8	1800	2,990	0.104	46.6	3.80	0.169	0.096	0.51	604
2.00	29.8		4,960	.209	90.8	3.85	.319	.098	1.06	606
2.01	29.7		7,480	.257	109.5	3.86	.385	.097	1.16	609
2.01	29.9		8,990	.309	128.9	3.86	.452	.097	1.29	610
1.99	29.7		10,470	.362	143.9	3.87	.509	.096	1.20	612
2.00	29.8		11,960	.413	160.7	3.89	.563	.097	1.24	612
2.00	29.8		13,480	.466	173.8	3.89	.607	.094	1.18	613
2.00	29.7		15,010	.517	182.3	3.89	.636	.094	1.14	615
2.00	29.7		16,980	.584	189.6	3.85	.662	.087	.95	618
1.99	29.8	1800	3,060	0.106	46.2	3.82	0.173	0.193	1.91	600
1.99	29.9		6,050	.209	91.2	3.80	.321	.194	2.10	599
2.01	29.9		7,540	.258	110.4	3.86	.385	.193	2.26	600
2.00	29.9		9,010	.311	127.4	3.87	.447	.194	2.34	599
2.00	29.8		10,510	.363	144.5	3.90	.505	.193	2.50	599
2.00	29.8		12,080	.414	161.9	3.89	.565	.194	2.28	600
2.01	29.9		13,450	.462	173.5	3.90	.601	.193	2.22	600
2.01	29.9		14,990	.515	181.5	3.87	.634	.194	2.10	801
2.01	29.6		16,950	.583	186.6	3.86	.661	.194	1.29	602
1.46	29.6	1200	2,990	0.104	47.4	3.82	0.171	0.330	5.01	578
2.00	29.9		6,000	.206	89.6	3.88	.313	.330	5.54	580
2.00	29.8		7,510	.259	106.9	3.88	.385	.331	5.56	580
1.99	29.8		9,000	.311	127.4	3.88	.448	.331	5.52	581
2.00	29.8		10,490	.361	142.3	3.88	.498	.332	5.40	581
1.99	29.9		11,970	.414	159.1	3.90	.536	.332	5.19	582
2.01	29.8		13,470	.463	172.8	3.90	.568	.331	5.11	583
2.00	29.9		15,000	.516	176.9	3.89	.572	.331	4.66	584
2.01	29.9		16,980	.584	187.2	3.82	.664	.331	4.17	586

Pressure ratio p_1/p_6	Total inlet pressure p_1 (in. Hg abs.)	Total inlet temperature T_1 (°R)	Turbine speed N (rpm)	Blade-to-jet speed ratio U/V	Shaft power (hp)	Gas flow W_t (lb/sec)	Turbine efficiency η	Cooling-air flow W_c (lb/sec)	Cooling-air pressure drop (in. Hg)	Cooling-air inlet temperature (°R)
2.00	30.0	1600	3,000	0.089	47.3	3.33	0.184	0.193	3.66	632
2.00	30.0		6,020	.179	91.2	3.40	.274	.194	3.58	632
2.00	30.0		7,530	.224	111.6	3.39	.335	.193	3.67	632
2.01	30.0		9,000	.267	129.4	3.41	.384	.192	3.77	632
2.01	30.0		10,500	.312	146.5	3.41	.436	.193	3.81	632
2.01	30.0		12,000	.357	166.5	3.42	.493	.194	3.67	632
2.01	30.0		13,490	.401	178.2	3.42	.527	.194	3.49	632
2.01	30.0		15,010	.446	192.9	3.43	.568	.194	3.30	632
2.01	30.1		16,990	.508	207.9	3.41	.615	.194	2.91	632
1.99	29.9	1600	3,020	0.090	47.8	3.34	0.186	0.328	2.32	630
2.01	29.9		6,000	.178	91.6	3.39	.273	.380	2.32	632
2.01	29.8		7,520	.223	112.1	3.39	.334	.312	2.80	632
2.01	29.9		8,998	.268	130.2	3.39	.388	.321	2.39	632
2.01	29.9		10,500	.312	147.5	3.40	.440	.321	2.45	632
2.02	30.0		11,990	.355	166.2	3.41	.480	.325	2.61	632
2.01	30.0		13,480	.401	180.4	3.38	.516	.321	2.61	632
2.01	30.0		14,990	.445	193.9	3.42	.572	.325	2.76	632
2.02	30.1		16,980	.502	210.0	3.41	.617	.331	3.04	632
2.00	30.0	1600	2,990	0.089	47.9	3.32	0.146	0.468	8.07	632
2.00	29.8		6,010	.179	91.5	3.38	.275	.411	8.00	632
2.00	30.0		7,490	.223	112.5	3.40	.334	.410	7.88	632
2.01	30.0		9,010	.268	133.0	3.40	.396	.416	7.85	632
2.01	30.0		10,500	.312	148.6	3.40	.442	.414	7.84	632
2.01	30.0		12,030	.358	165.7	3.40	.494	.414	7.25	632
2.01	30.0		13,460	.400	178.6	3.42	.527	.416	7.05	632
2.00	30.0		14,980	.446	190.6	3.41	.566	.414	6.72	632
2.01	30.0		17,010	.505	206.4	3.46	.603	.480	6.27	632
2.00	30.1		12,060	.359	166.6	3.40	.577	.412	7.21	632
2.00	29.8	2000	2,970	0.079	47.3	3.00	0.127	0.331	5.62	632
2.00	29.8		5,940	.158	92.0	3.01	.247	.333	5.90	632
2.01	29.8		7,540	.200	113.4	3.00	.304	.333	5.87	632
2.01	29.9		8,980	.236	135.9	3.03	.354	.333	5.87	632
2.02	29.8		10,490	.277	158.6	3.03	.403	.333	5.88	632
2.02	30.0		12,020	.318	173.0	3.03	.458	.330	5.80	632
2.02	29.8		13,550	.358	186.8	3.03	.497	.330	5.70	632
2.01	29.8		14,970	.397	201.2	3.03	.535	.330	5.58	632
2.01	30.0		16,980	.448	220.4	3.03	.586	.331	5.17	632
2.01	29.8	2000	3,040	0.081	49.0	2.99	0.132	0.315	7.76	632
2.02	29.8		6,030	.160	95.1	3.04	.251	.411	7.92	632
2.02	29.8		7,510	.199	112.4	3.05	.303	.411	7.94	632
2.01	30.0		9,000	.236	134.8	3.05	.355	.414	7.84	632
2.02	30.1		10,500	.277	154.0	3.06	.402	.408	8.00	632
2.01	29.9		11,990	.318	172.5	3.05	.455	.416	7.82	632
2.01	29.9		13,480	.356	187.0	3.05	.491	.419	7.58	632
2.01	30.0		15,010	.397	201.9	3.04	.531	.419	7.61	632
2.02	29.8		16,990	.449	219.8	3.05	.576	.429	7.04	632
1.44	29.8	1200	3,000	0.104	48.1	5.11	0.170	0.095	1.84	632
1.99	29.8		6,000	.207	120.7	5.17	.319	.094	2.34	632
1.99	29.7		7,510	.260	146.1	5.19	.385	.095	2.50	632
1.99	29.6		8,990	.311	162.1	5.18	.446	.095	2.73	632
2.00	29.8		10,490	.363	179.7	5.20	.499	.096	2.75	632
2.00	29.8		11,950	.412	210.9	5.18	.549	.095	2.77	632
2.00	29.8		13,500	.465	227.1	5.23	.601	.095	2.56	632
2.01	30.0		14,980	.515	242.1	5.20	.639	.095	2.48	632
2.00	30.0		17,000	.585	254.7	5.17	.684	.095	1.98	632
1.99	30.0	1200	3,000	0.104	51.4	5.12	0.170	0.184	3.24	632
1.99	29.7		6,080	.206	180.9	5.21	.312	.183	3.81	632
1.98	29.8		7,510	.260	145.5	5.21	.383	.192	3.97	632
2.00	30.0		8,990	.310	169.6	5.22	.442	.194	4.17	632
2.00	30.0		10,550	.363	191.2	5.20	.496	.187	4.09	632
2.00	30.0		12,020	.415	213.2	5.21	.557	.194	3.89	632
2.00	29.9		13,490	.465	231.7	5.24	.602	.194	3.58	632
2.00	29.9		15,030	.518	241.7	5.23	.630	.194	3.12	632
2.00	29.9		17,010	.586	258.2	5.16	.664	.193	2.30	632
1.97	29.9	1200	3,020	0.105	49.1	5.15	0.170	0.329	6.15	632
1.99	29.6		6,080	.206	180.4	5.20	.317	.327	6.58	632
2.00	29.7		7,580	.260	145.3	5.20	.383	.329	6.66	632
2.00	29.8		9,030	.312	170.4	5.20	.447	.324	6.66	632
2.00	30.0		10,500	.369	189.9	5.19	.493	.323	6.50	632
2.00	29.8		12,000	.414	213.2	5.21	.555	.325	9.15	632
2.00	29.6		13,490	.465	231.7	5.25	.595	.325	2.76	632
2.01	29.9		15,020	.516	241.5	5.21	.628	.322	2.48	632
2.00	29.9		17,000	.586	252.7	5.19	.663	.324	4.48	632

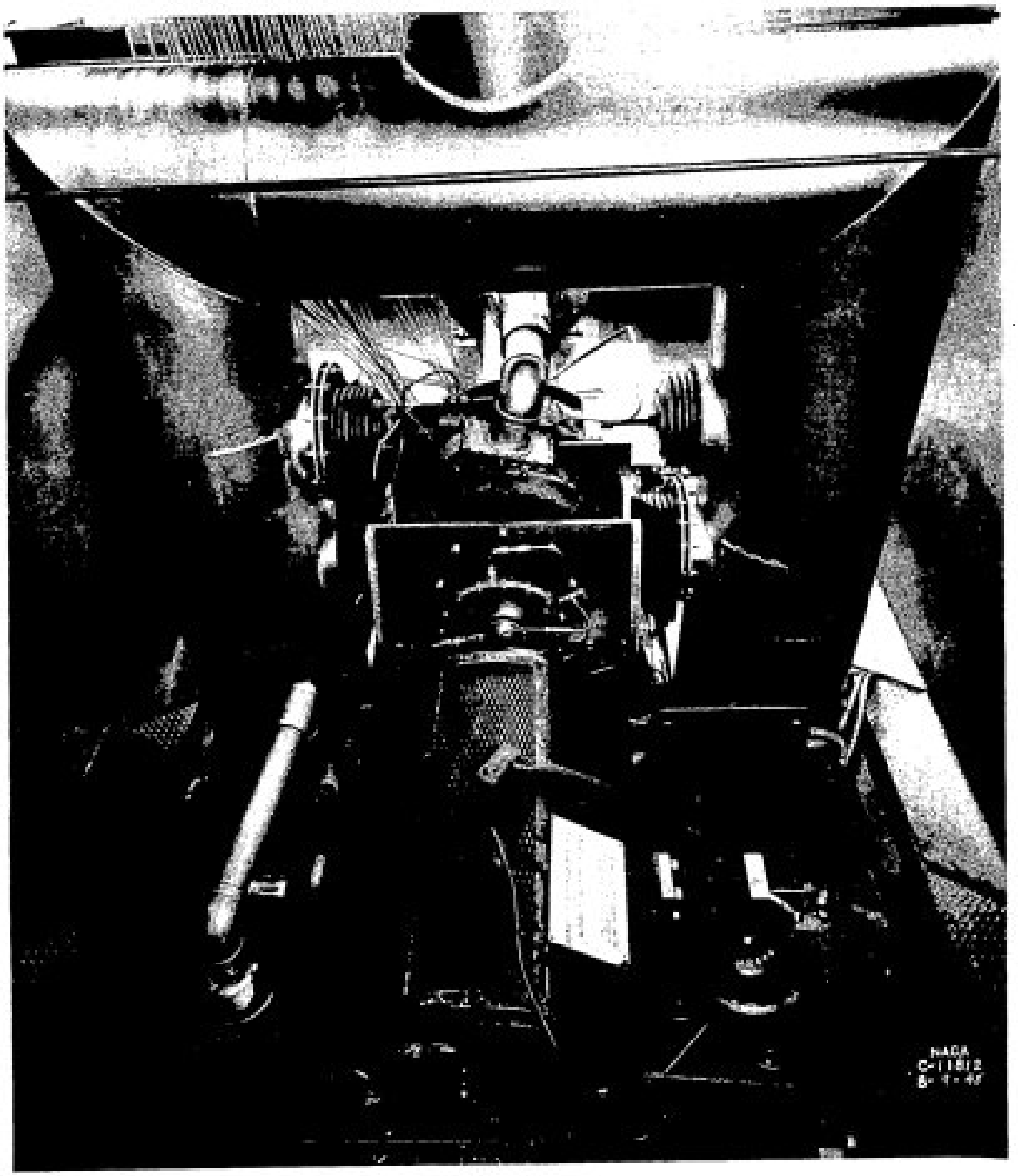
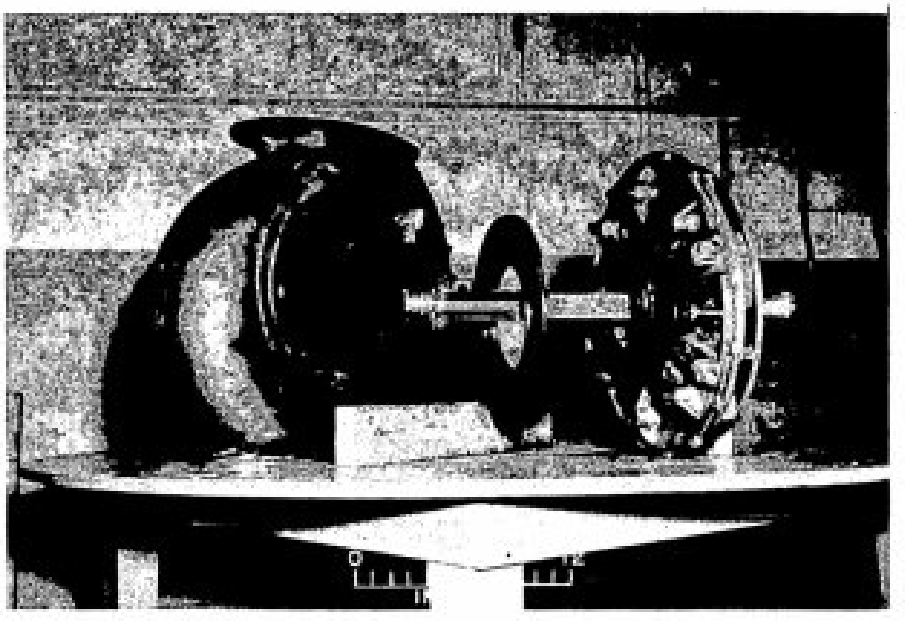
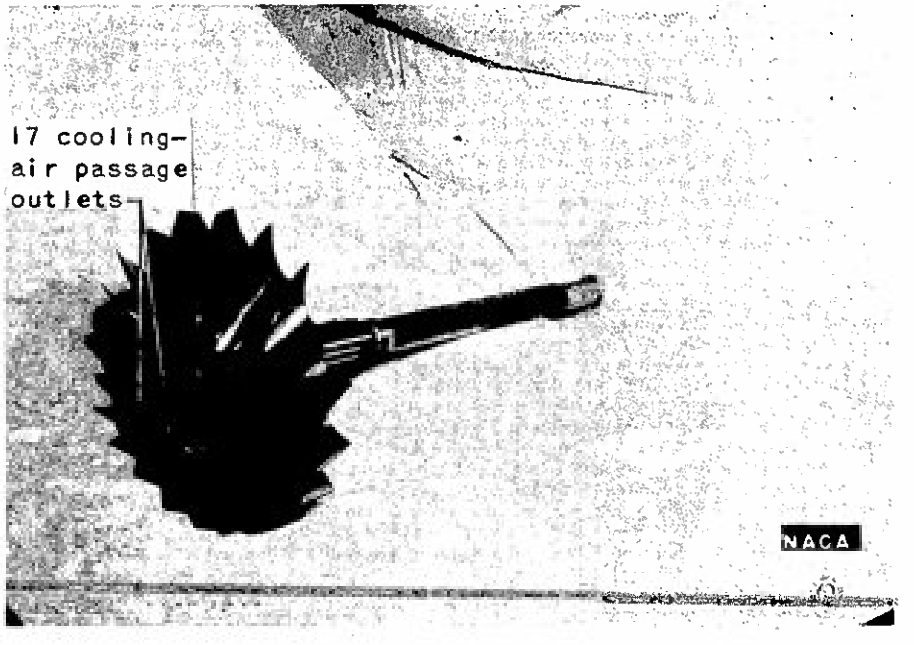


Figure 1. - Test setup of radial-flow exhaust-gas turbosupercharger turbine.



(a) Nozzle box, turbine wheel and shaft, wheel-case center cover, and rear-bearing support.



(b) Turbine wheel showing cooling-air passage outlets.

Figure 2. - Components of radial-flow exhaust-gas turbosupercharger turbine.

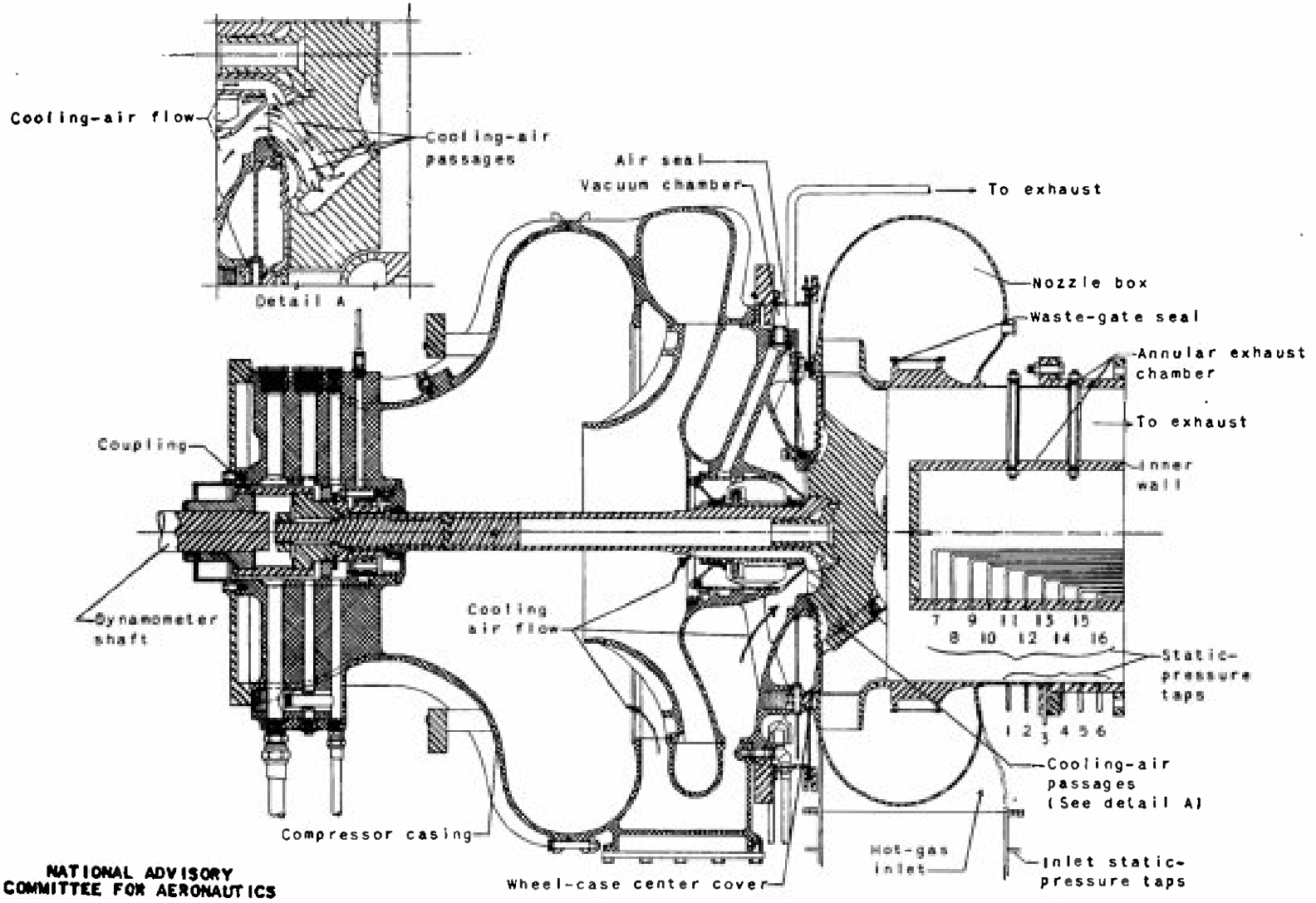


Figure 3. - Schematic drawing of modified turbosupercharger assembly.

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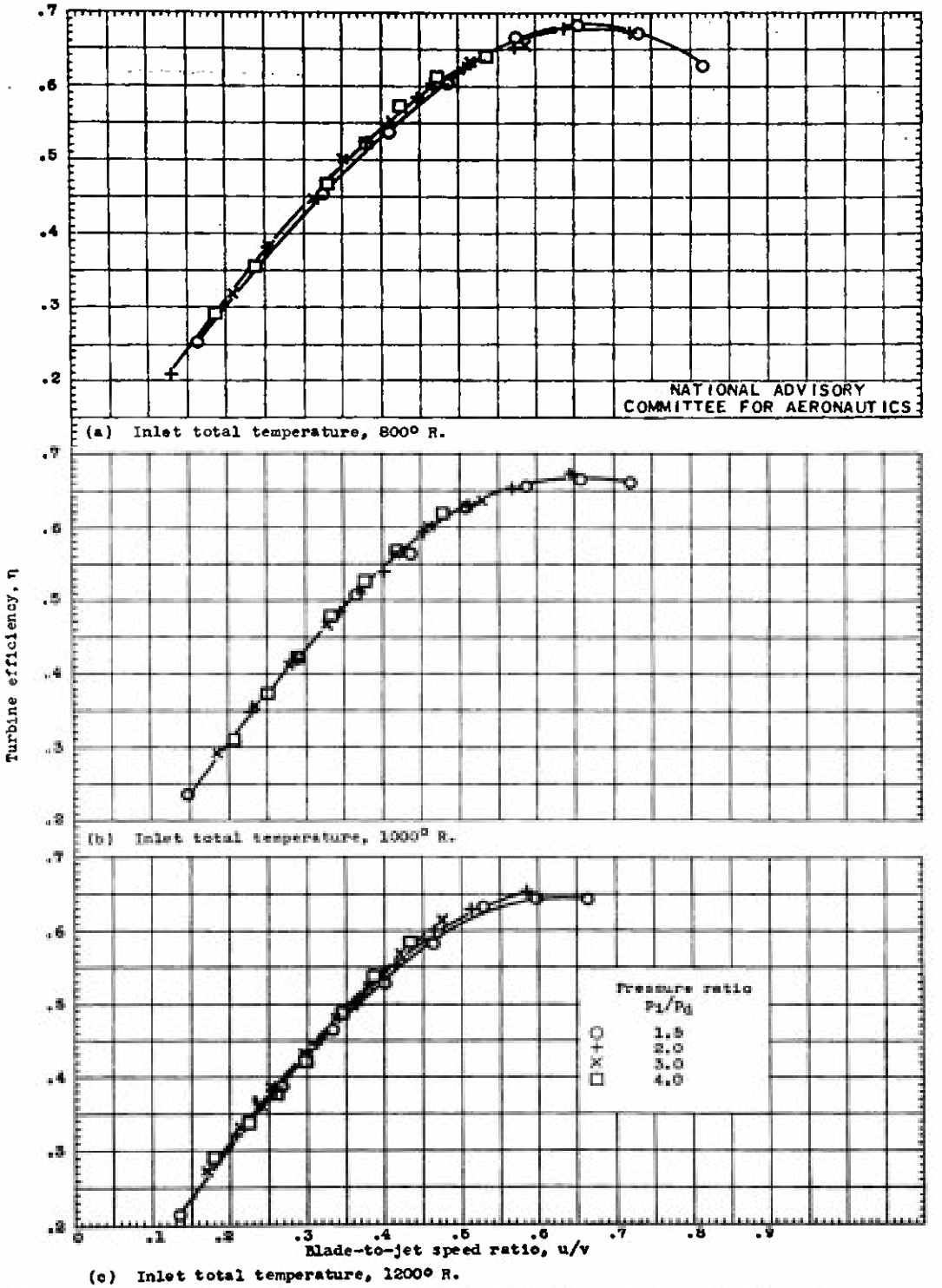
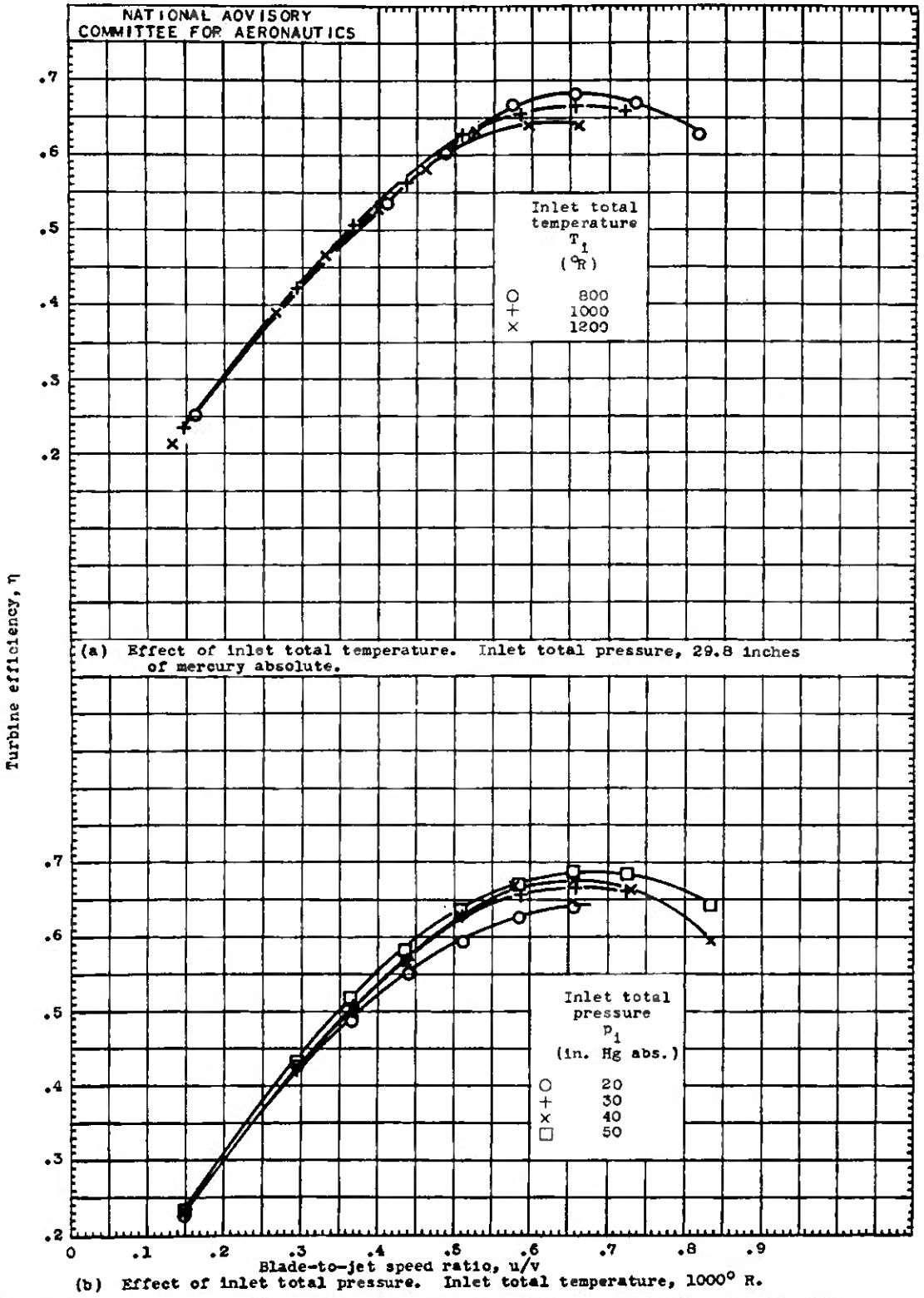


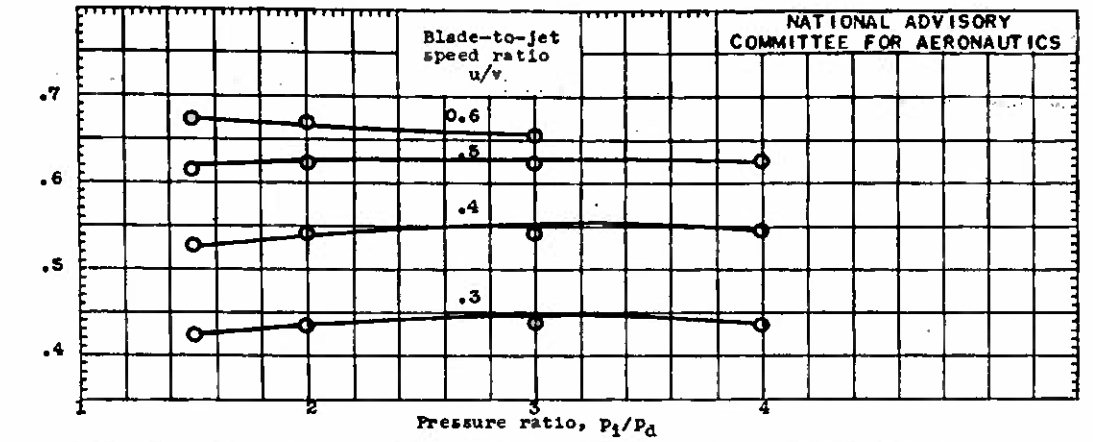
Figure 4. - Variation of turbine efficiency with blade-to-jet speed ratio for various inlet total temperatures and pressure ratios. Inlet total pressure, 29.8 inches of mercury absolute.



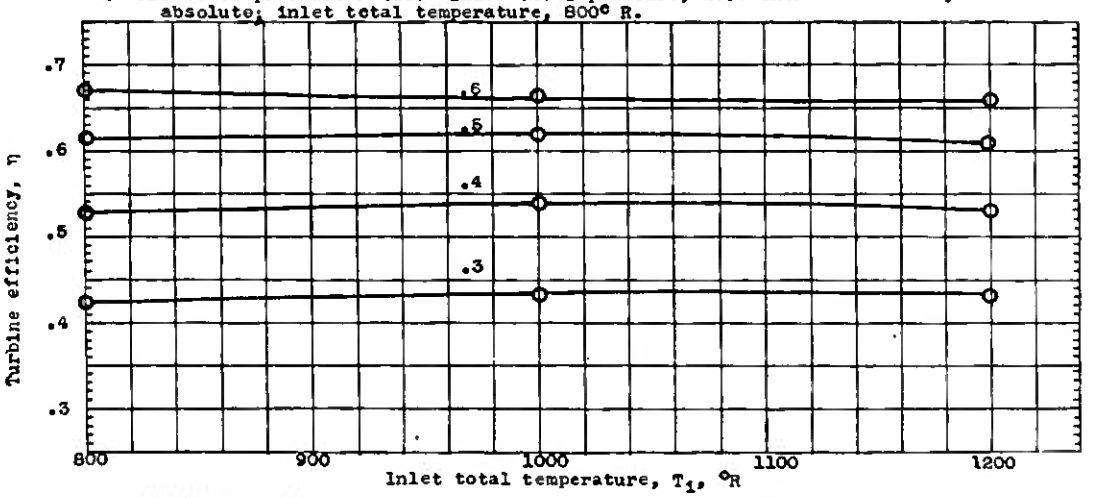
(a) Effect of inlet total temperature. Inlet total pressure, 29.8 inches of mercury absolute.

(b) Effect of inlet total pressure. Inlet total temperature, 1000° R.

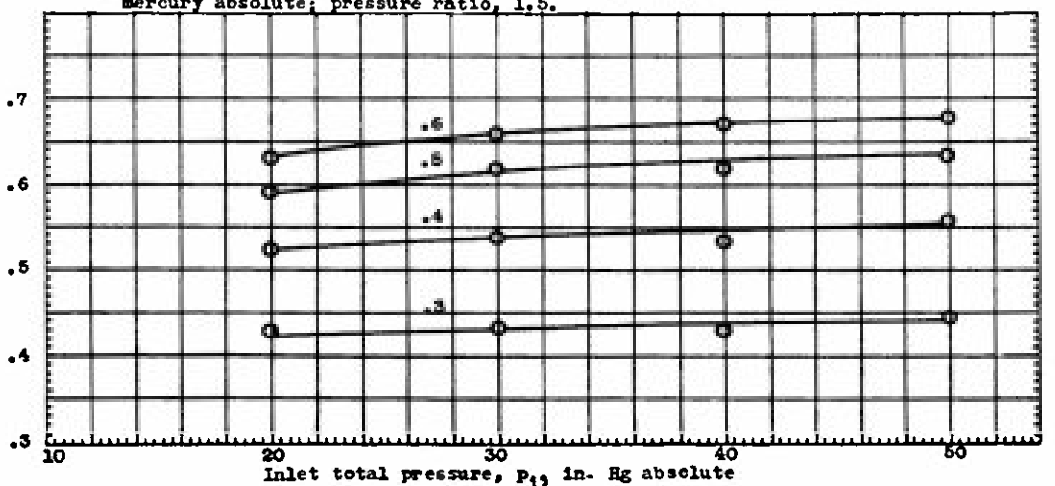
Figure 5. - Variation of turbine efficiency with blade-to-jet speed ratio for various inlet total temperatures and inlet total pressures. Pressure ratio, 1.5.



(a) Effect of pressure ratio. Inlet total pressure, 29.7 inches of mercury absolute; inlet total temperature, 800° R.



(b) Effect of inlet total temperature. Inlet total pressure, 29.7 inches of mercury absolute; pressure ratio, 1.5.



(c) Effect of inlet total pressure. Inlet total temperature, 1000° R; pressure ratio, 1.5.

Figure 6. - Variation of turbine efficiency with pressure ratio, inlet total temperature, and inlet total pressure.

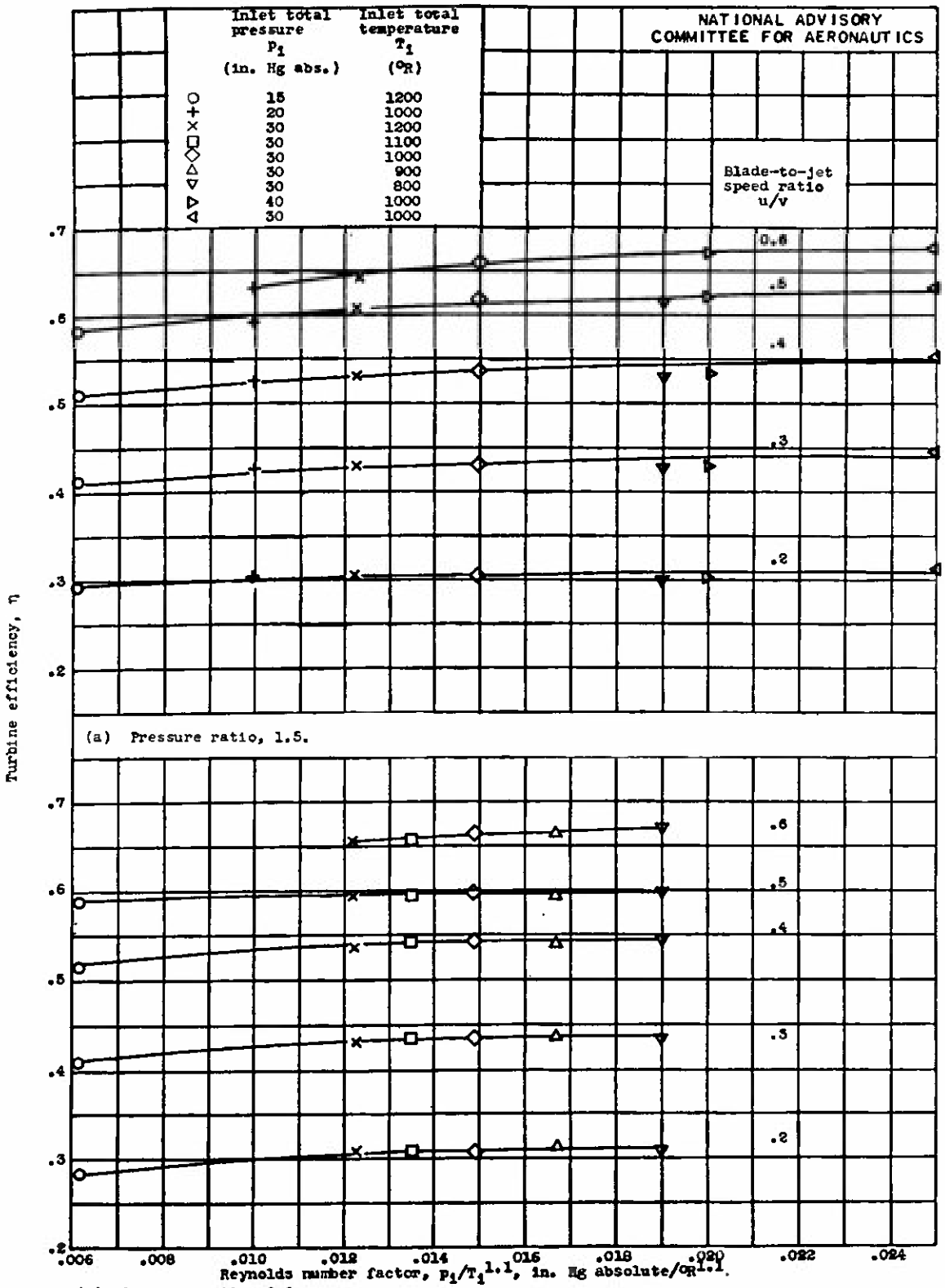
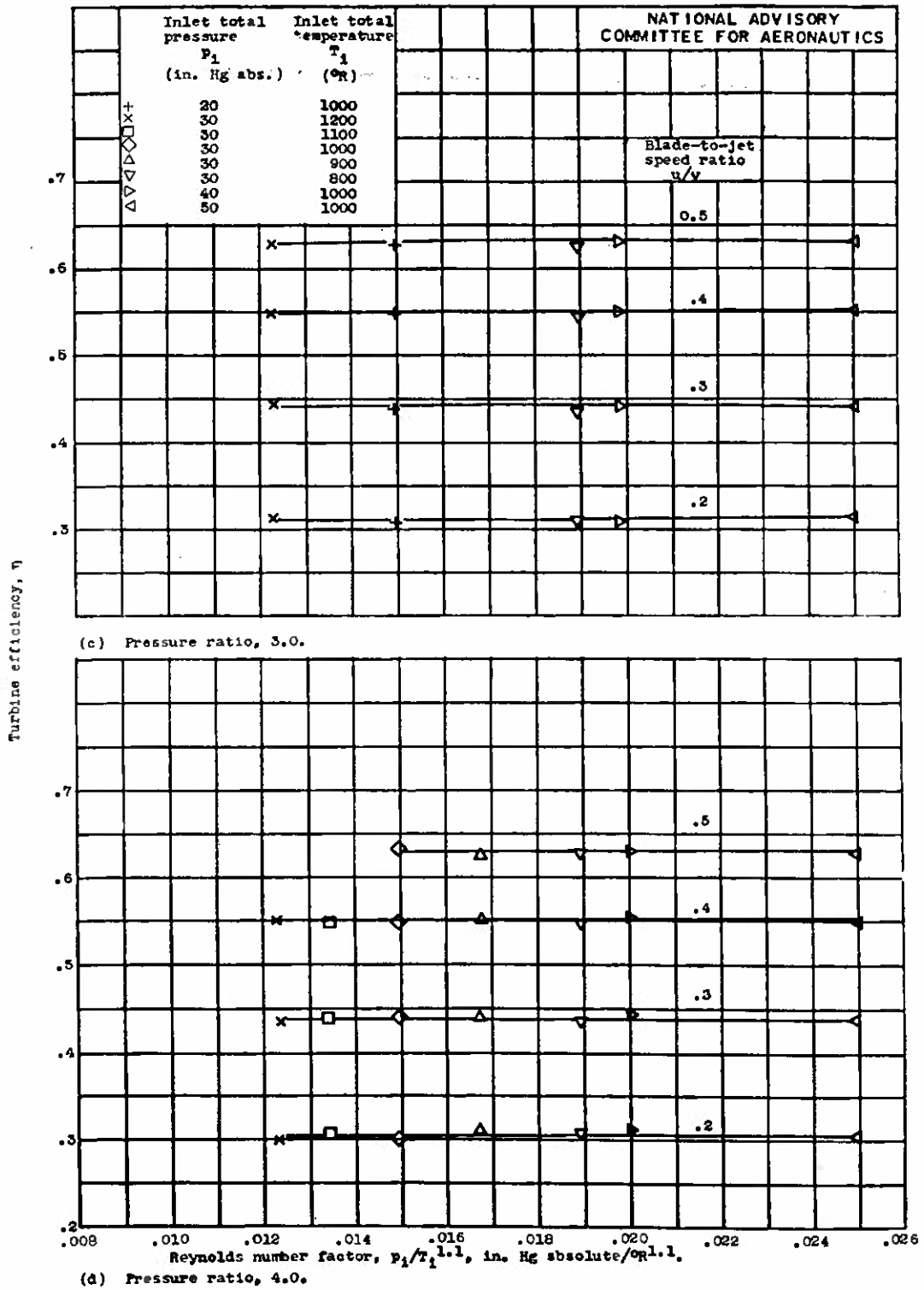


Figure 7. - Variation of turbine efficiency with Reynolds number factor.



(c) Pressure ratio, 3.0.

(d) Pressure ratio, 4.0.

Figure 7. - Concluded.

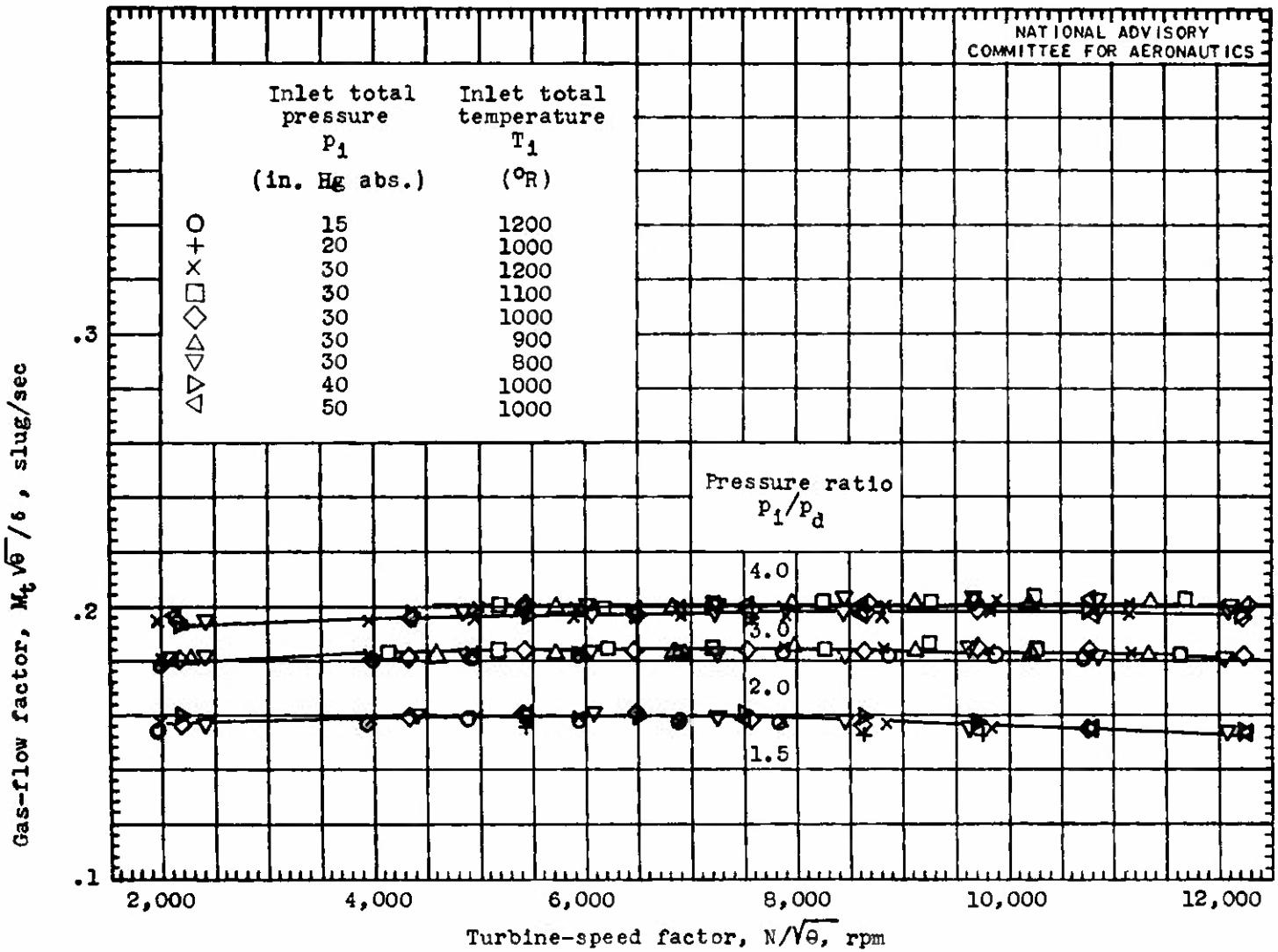


Figure 8. - Variation of gas flow with turbine-speed factor.

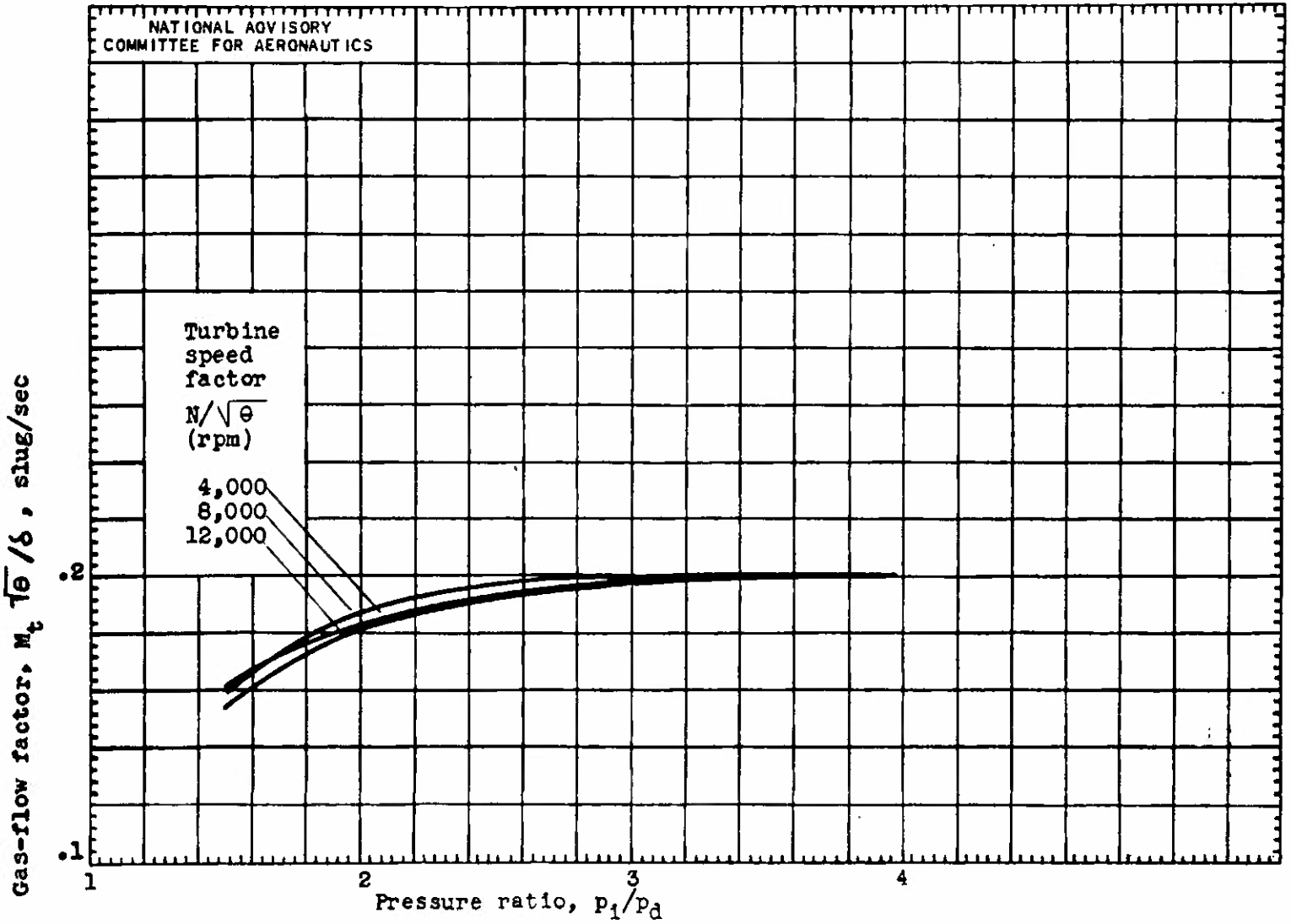


Figure 9. - Variation of gas flow with pressure ratio.

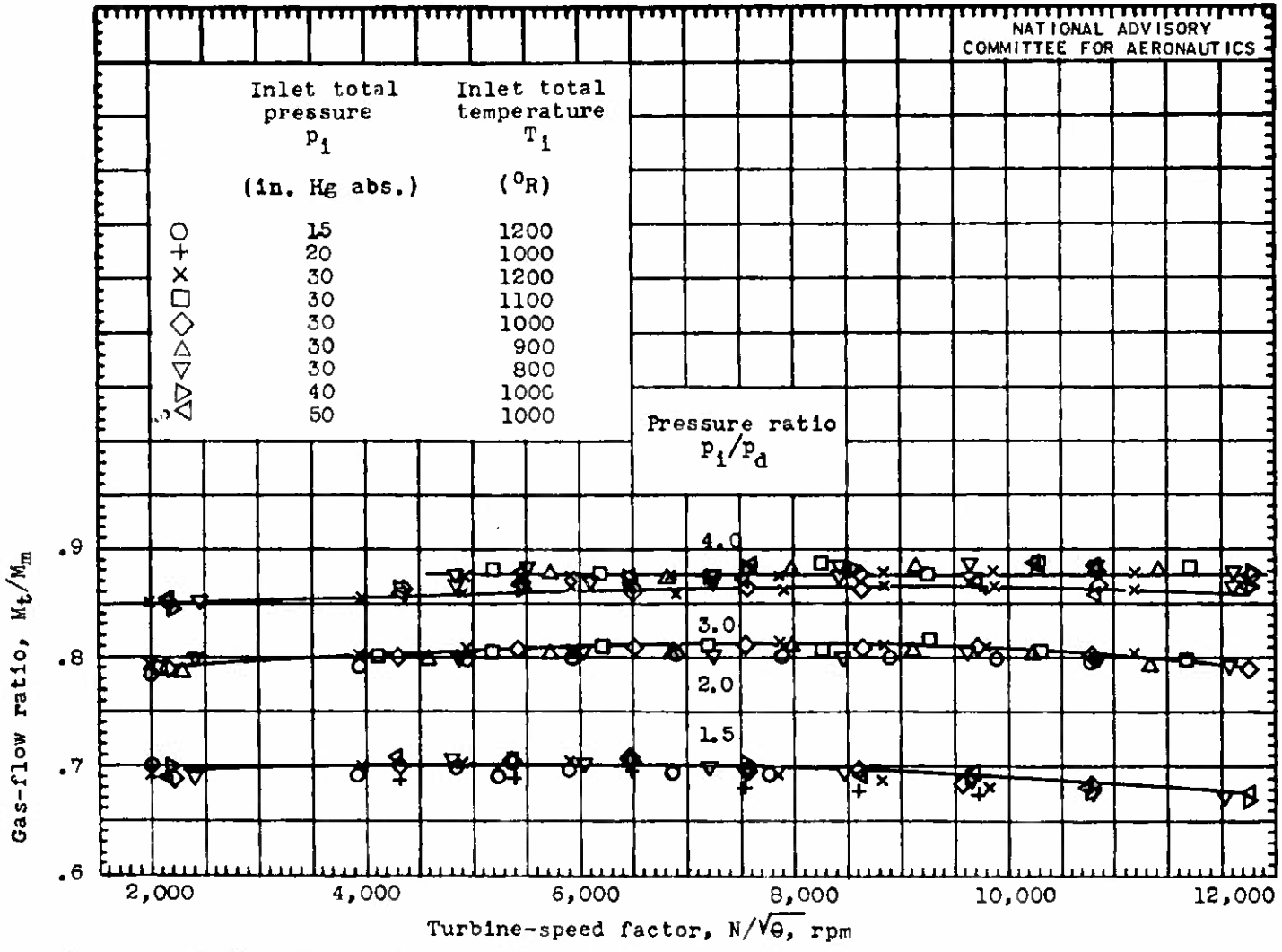


Figure 10. - Variation of the gas-flow ratio M_t/M_m with the turbine-speed factor. $M_m \sqrt{\theta}/\delta$ = 0.228 slug/sec.

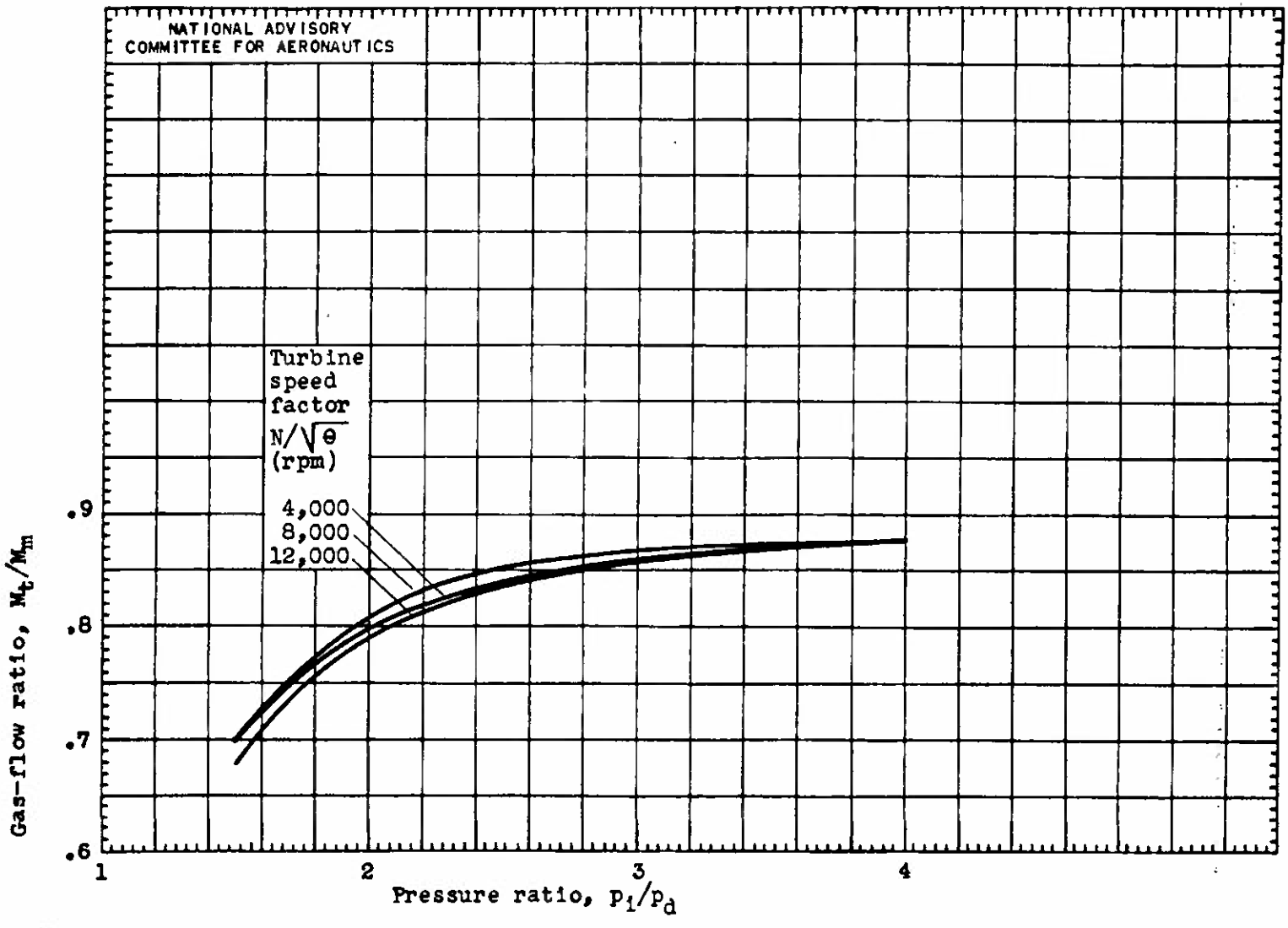


Figure 11. - Variation of gas-flow ratio M_t/M_m with pressure ratio.

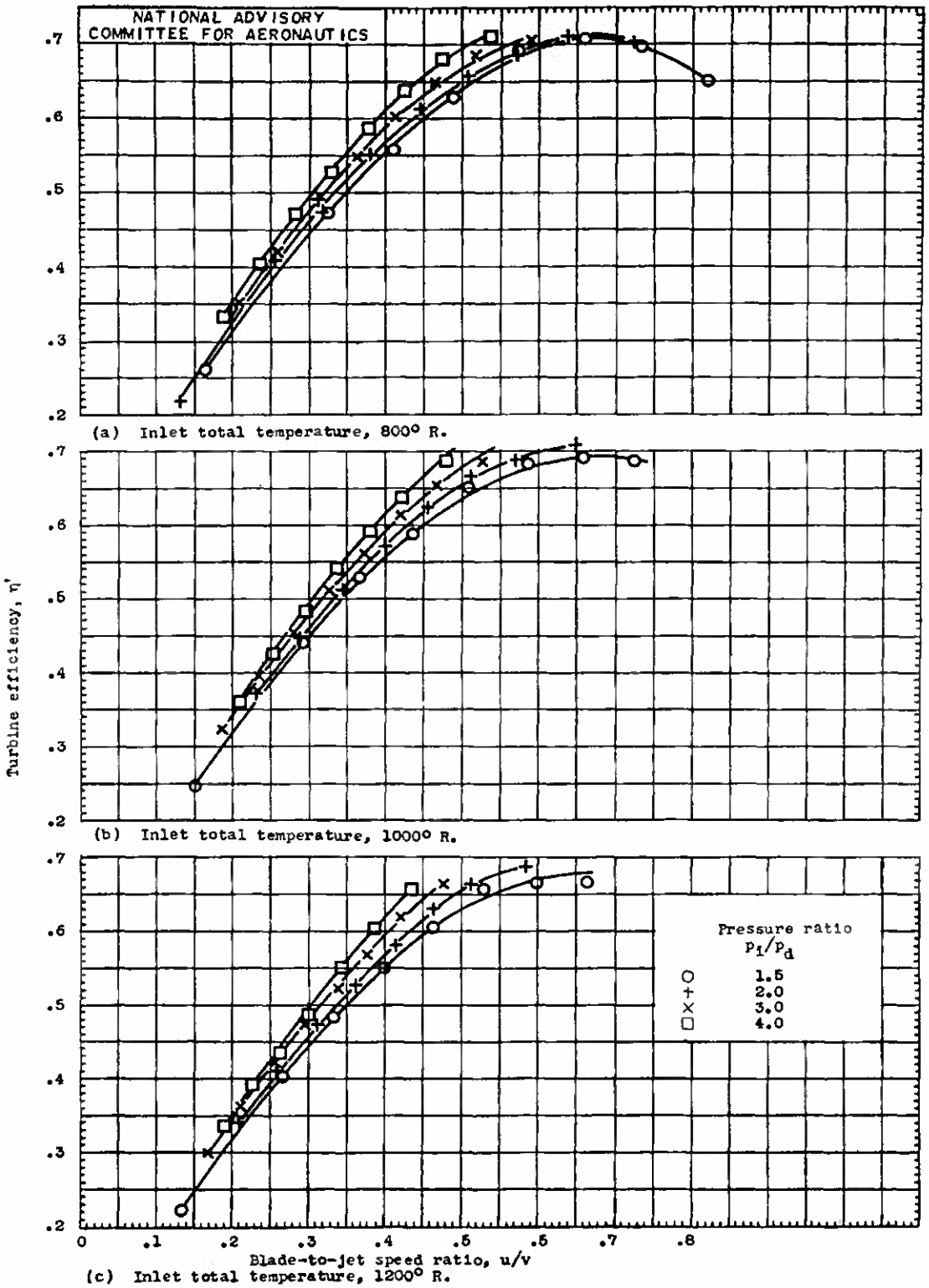


Figure 12. - Variation of the turbine efficiency η' with blade-to-jet speed ratio for various inlet total temperatures and pressure ratios. Inlet total pressure, 29.8 inches of mercury absolute.

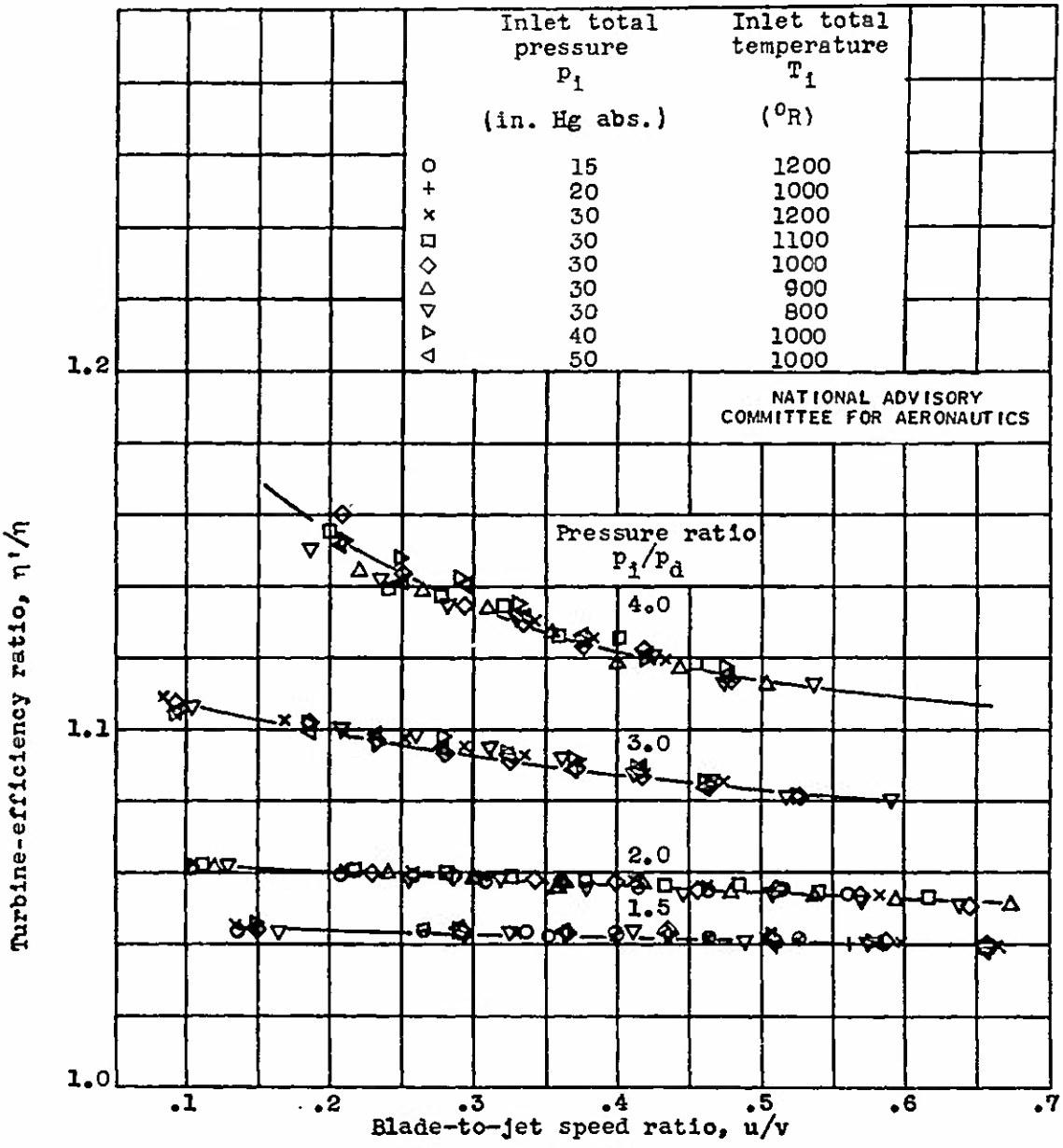


Figure 13. - Variation of turbine-efficiency ratio η'/η with blade-to-jet speed ratio for various pressure ratios.

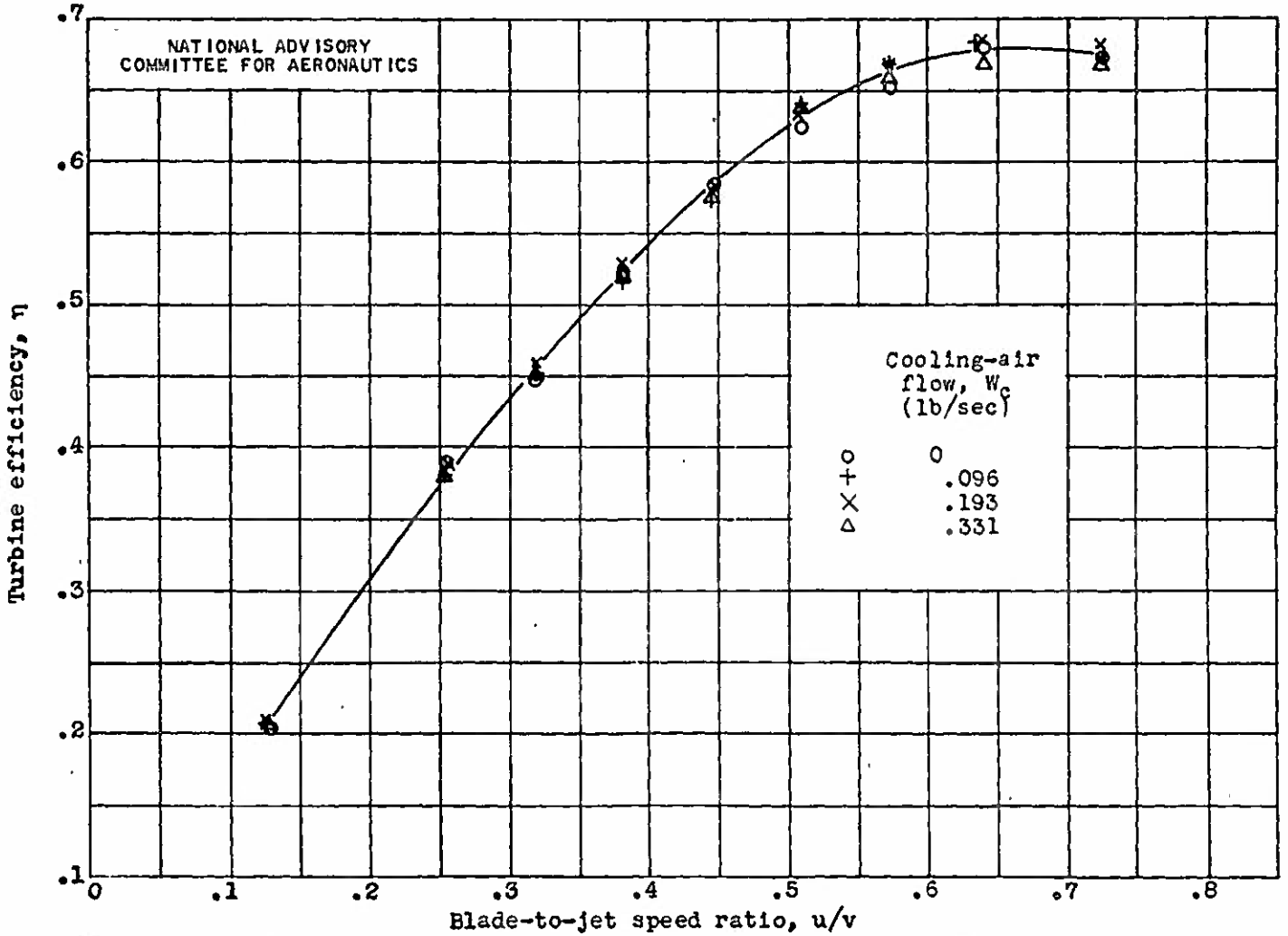


Figure 14. - Variation of turbine efficiency with blade-to-jet speed ratio for various cooling-air flows. Inlet total temperature, 800° R; inlet total pressure, 29.8 inches of mercury absolute; pressure ratio, 2.0.

TITLE: Efficiency of a Radial-Flow Exhaust-Gas Turbosupercharger Turbine with a 12.75-Inch Tip Diameter

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ABSTRACT:

A performance test was conducted on a radial-flow exhaust gas turbosupercharger turbine with a 12.75 in. tip diameter, at inlet pressures of 15-50 in. of mercury absolute, inlet temperatures from 800° to 2000°R, turbine speeds from 3000 to 17,000 rpm, pressure ratios from 1.5 to 4.0 and cooling air flow from 0 to 10% of turbine gas flow. The efficiency increased aboout 4.5 points at blade-to-jet speed ratios of 0.5 and 0.6 as inlet pressure increased from 20 to 50 in. of mercury absolute. Cooling-air flow had no measurable effect on turbine efficiency within the accuracy of the tests in the test range. Data for all the tests were tabulated and curves were plotted.

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